Banking under large excess reserves

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Abstract

This paper examines the impact of large-scale asset purchase programs (LSAPs), commonly known as quantitative easing (QE), on bank lending in the Eurozone. While LSAPs have significantly increased central bank reserves held by commercial banks, the effect on lending is ambiguous due to regulatory leverage limits that may cause excess reserves to crowd out loans. Moreover, LSAPs increase the volume of short-term, unstable wholesale deposits, worsening banks' funding conditions by raising the proportion of less stable liabilities. We develop a structural model incorporating imperfect competition in credit and deposit markets and balance sheet costs arising from Basel III regulatory constraints. Unlike traditional models, we treat regulatory requirements as costs that escalate as banks approach minimum thresholds, allowing us to quantify how excess reserves contribute to these costs. Estimating the model using French data from 2013 to 2021, we find that when interest rates are low and balance sheets are constrained, regulatory costs become substantial. LSAPs increased the marginal cost of long-term lending by up to 16 basis points in Q4 2021 in France. Counterfactual analyses suggest that if central bank reserves had been maintained at around 2 trillion euros instead of 4 trillion, aggregate bank lending could have been approximately 5% higher in Q4 2021. These findings imply that LSAPs may inadvertently constrain bank lending due to regulatory costs associated with excess reserves.

JEL classification: E52, E58, G20, G21, G28.

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1 Introduction

Upon reaching the zero lower bound on interest rates, the world's major central banks turned to large-scale asset purchase programs (LSAPs) – commonly known as quantitative easing (QE) – to stimulate the economy. Initially viewed as unconventional and temporary measures, these programs now constitute a permanent fixture in the policy toolbox of central banks. LSAPs have led to a massive expansion of the volume of central bank reserves held by commercial banks, as depicted in figure 1. Despite the widespread adoption of LSAPs, the impact of excess reserves resulting from these policies on banks' lending behavior remains ambiguous. On one hand, additional central bank reserves may alleviate liquidity needs and consequently encourage banks to engage in liquidity transformation–that is, to lend more. On the other hand, since the size of the balance sheet is constrained by regulatory limits on leverage, additional reserves might reduce available balance sheet space for loans. Furthermore, LSAPs increase the volume of short-term, unstable wholesale deposits in the banking system, which deteriorates banks funding conditions by raising the proportion of less stable liabilities. Thus, whether LSAPs are expansionary or contractionary for bank lending remains an empirical question, which is the focus of this paper.

To address the underlying trade-offs, we develop a structural model that incorporates imperfect competition in the credit and deposit markets, as well as balance sheet costs driven by regulatory constraints. We estimate the model on French and Eurozone data. Intuitively, reserves are liquid assets used as collateral to back up unstable deposit funding, enabling banks to potentially expand their balance sheets by issuing more deposits to fund additional loans. However, banks' leverage is constrained by regulation – they cannot expand their balance sheet above a multiple of their core equity: there is a tipping beyond which additional central bank reserves no longer facilitate balance sheet expansion. After this tipping point, reserves can be detrimental to loan issuance, as they take up space on the asset side of the balance sheet, which cannot be expanded anymore. An excessive amount of central bank reserves might therefore crowd out other assets, limiting banks' ability to extend new loans.[1]. While the large increase of reserves has been shown to crowd out bank lending in the US (Diamond, Jiang, & Ma, 2022), we extend literature in several ways.

First, we directly incorporate the Basel III regulatory framework into our analysis. Our structural model allows for the quantification of the cost of each Basel III requirement, and specifically how much excess reserves injected during LSAPs contribute

[1]Note that while the leverage constraint is instrumental in this intuitive example, it is not necessary per se. We present a theoretical model in A where the deposit market is limited in size, which leads to a non-linear increase in the cost of deposit funding as the banks grow their balance sheets. in such case, balance sheet space is also increasingly costly as the balance sheet grows, and reserves crowd-out other assets.

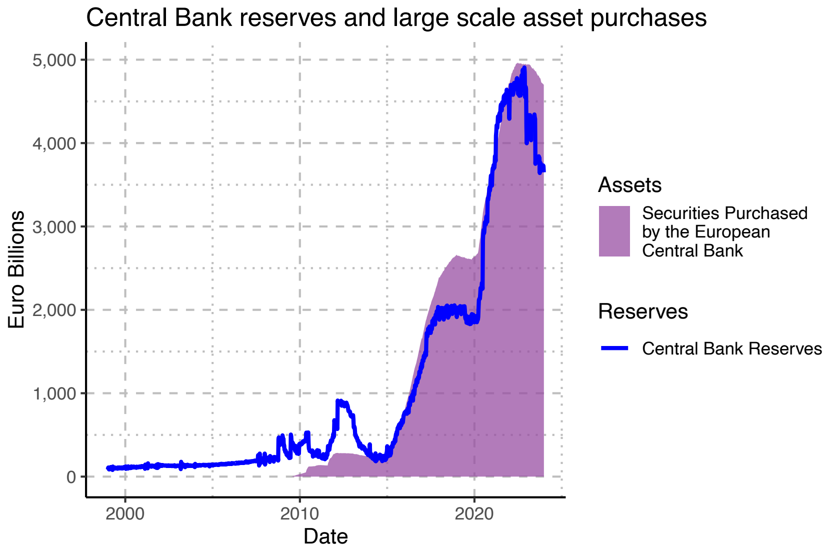


Figure 1: Central bank reserves in the Eurozone

In this figure, the solid line plots the aggregate quantity of central bank reserves in the Eurozone. The area graph plots the quantity of securities purchased by the European Central Bank as a part of its asset purchases programs.

Data from the ECB data platform.

to these regulatory costs. Our approach models regulatory requirements not as rigid constraints but as costs that increase as banks get closer to minimum regulatory thresholds, enabling us to empirically quantify how banks adjust their portfolios in response to these requirements. Three regulatory constraints capture the essence of the frictions we are interested in: the liquidity coverage ratio (LCR), which measures the liquidity situation of the bank; the leverage ratio (LEV), which measures the size of the balance sheet relative to core equity; and the net stable funding ratio (NSF), which ensures that the maturity profile of assets and liabilities are aligned – no maturity mismatches. When the holdings of reserves by a specific bank increase, the liquidity of the bank – as measured by the LCR – improves. On the other hand, the leverage of the bank increases, which degrades the leverage ratio. Further, the large volume of wholesale deposits resulting from LSAPs (see table 2) increases the risk of liquidity mismatches – which worsens the NSF ratio. Banks face a trade-off between liquidity, leverage, and stable funding as reflected in Basel ratios. Our estimates show that when interest rates are low and balance sheets constrained, the relative costs of regulation can get comparatively very large. In 2020 and 2021, regulation represented the vast majority of the cost of providing credit. The contribution of LSAPs to the marginal cost of providing long term lending amounted to 16 basis points in Q4 2021 in France, at a time where the interest rate on new mortgages or new corporate loans was sitting around 1.15%.

Second, we show that the heterogeneous allocation of reserves induced by LSAP play an important role. As the system becomes flush with excess reserves, it becomes impossible for banks to offload the reserves they have been endowed with. There is simply insufficient borrowing capacity in the interbank market, as most banks are teeming with liquidity. As such, regulatory costs were unevenly distributed: large banks that are more exposed to QE transactions faced as much as a 40 basis point increase in their marginal cost of providing long-term loans. Further, our model is rationalizes the observed transactions on the interbank market: net borrowers of reserves have a liquidity constraint that is tighter relative to their leverage constraint than net lenders of reserves. In short, there are gains from trade. Nonetheless, the aggregate potential for profitable trades decreases as the volume of excess reserves increases[2].

Third, to the best of our knowledge, we are the first to structurally quantify the "reserve supply channel" in the Eurozone. This is particularly significant given the substantial institutional differences between the US and European banking systems. For instance, the Eurozone lacks a reverse repo facility, meaning that reserves cannot leave the banking system. Moreover, large European banks are not subject to the Volcker Rule[3] and typically do not have separate investment banking and retail/commercial banking divisions. Consequently, they can fund their asset portfolios through deposits and freely substitute between supplying credit and investing in riskier assets such as bonds and stocks. Such substitution between lending and financial market investments can have significant equilibrium effects since the European banks hold more than 30% of the corporate bonds and more than 35% of the sovereign bonds in the Eurozone (Koijen et al., 2021). Moreover, unlike the Federal Reserve, the ECB implemented negative interest rates in the Eurozone as a part of their unconventional monetary policy. Negative interest rates can increase the cost borne by banks since the zero lower bound stops banks from passing the costs of negative interest-bearing reserves as well as costly regulatory requirements onto their depositors.

Finally, our approach allows us to quantify how much banks will adjust their holdings of government bonds and other safe assets as a result of LSAPs. Indeed, as central bank reserves fulfill the same role of liquidity collateral as these assets, banks reduce their holdings of government bonds as their holding of reserves increase. This dampens the effect of QE, as the net impact of asset purchases on the bond market is smaller than the gross volume of purchases suggests. A corollary is that quantitative tightening – the reversal of asset purchases – might be less destabilizing than commonly

[2]Note that while we don't directly study this, there are also implications for financial stability. While the aggregate amount of liquidity is large, it is unequally spread out. In the case of a market upheaval, the banks that need liquidity the most might be different from the bank with the most liquidity. As the quantity of unstable wholesale deposits increased considerably, it is unclear whether excess reserves make the banking system more stable as a whole. See Acharya et al., 2023 for a discussion.

[3]The Volcker Rule, that refers to section 619 of the Dodd-Frank Wall Street Reform and Consumer Protection Act of 2010, forbids US banks from funding their trading activity using deposits. Nothing comparable exists in Europe. Further, the US banking industry has a history of separation of retail banks and investment banks, starting with the Glass-Steagall act of 1933, which still shapes the US banking industry and regulatory framework today.

thought.

Our empirical analysis required us to overcome substantial data integration challenges. We meticulously combined multiple regulatory datasets, interest rate information, and credit registry data to construct a comprehensive dataset of French bank balance sheets from 2013 to 2021. This effort involved bridging disparate sources to capture detailed information on various financial products, including different types of loans and deposits. By hand-constructing this dataset, we ensure accurate and granular micro-level structural parameter estimates: The French banking system accounts for almost one-third of the Eurozone banking sector and is thus likely to be representative of the Euro-area bank behavior more generally.[4] Additionally, we compiled a second dataset encompassing the 152 largest banks in the Eurozone by merging data from BankFocus, the European Banking Authority, and the ECB. Although less granular, this aggregated dataset provides a comprehensive overview of the Eurozone banking sector. This enables us to use our structural parameter estimates to compute counterfactuals at the Eurozone level.

Before developing the structural model, we first show through reduced-form evidence that large quantities of reserves lead to a decline in lending volume. To address various endogeneity concerns, we develop an instrument for bank exposure to QE transactions and borrow the estimation methodology from Khwaja and Mian, 2008. The results are striking: reduced-form estimate suggest that up to 15% of bank credit provision to firms has been crowded out by LSAPs. To further understand the trade-offs involved, and compute sharper estimates of the equilibrium impact of LSAPs, we then introduce a structural model.

Our model is, at its core, a Monti-Klein (Klein, 1971; Monti et al., 1972) model of the banking industry, summarised in the figure 2 diagram. Banks choose an optimal portfolio of assets and liabilities to maximize their return on equity, compete in the lending and deposit markets, and are subject to regulatory constraints. In our model, banks are financed using a combination of deposits, wholesale funding and equity, and can invest in reserves, bank lending, and marketable securities. The banks have mean-variance preferences and they choose their asset portfolio in accordance with their bank-specific risk aversion[5]. Moreover, we model the unobservable costs faced by the bank as a function of the regulatory environment. Our comprehensive balance sheet data allows us to compute the regulatory ratios directly using a set of regulatory weights. At is costly for banks to fail to meet regulatory requirements, and having a buffer is preferable, we model regulatory shadow costs that grow when banks near

[4]In 2021 Q4, the total assets of French banks were 8.5 trillion, while the total assets of Eurozone banks were 27.9 trillion. https://www.ecb.europa.eu/press/pr/date/2022/html/ecb.pr220623~5a96b94bc7.en.html

[5]Consider that banks have different levels of access to the derivative markets, different hedging technologies, and even different costs of equity.

their regulatory limits. Since we directly compute regulatory ratios from observed data, we can quantify how much excess reserves contributes to the cost of regulation. Crucially, in our model, reserves are tradeable at a cost on the interbank market, with larger trades being associated with larger transaction costs. These transaction costs could be interpreted as higher counterparty monitoring costs (Dell'Ariccia, Laeven, & Marquez, 2014) or as the price pressure resulting from a larger order on the market (Gârleanu & Pedersen, 2013).

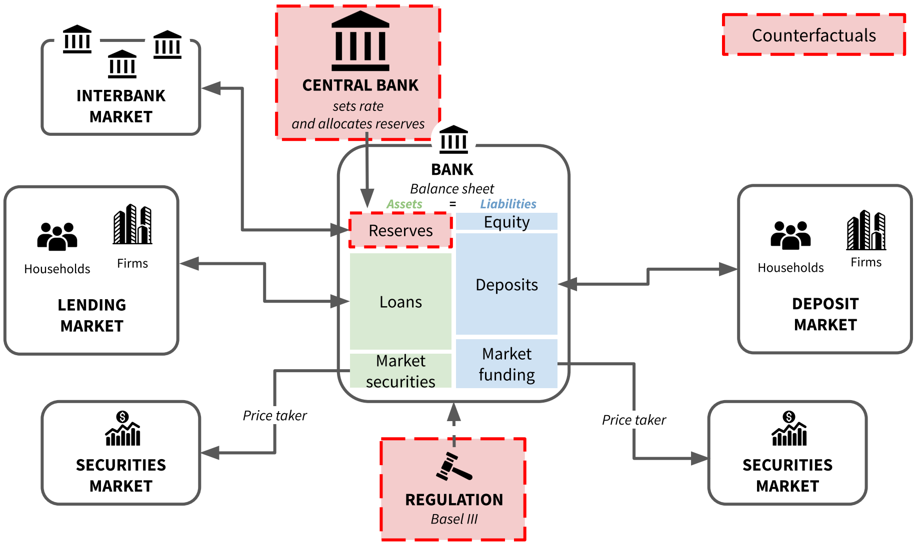


Figure 2: Model of the banking industry
Red, dashed frames highlight the exogenous parameters that we vary in our counterfactual scenarios.

Estimation proceeds in two steps. First, we use demand estimation techniques from the empirical IO literature to estimate the demand functions for deposits and loans. This is non-trivial, as the interest rates set by banks respond endogenously to shifts in demand. To address this endogeneity, we instrument bank rates with bank-specific instruments,including granular IVs (Gabaix & Koijen, 2024) and Hausman-like instruments (Hausman, 1994; Nevo, 2001). In the demand system we estimate, banks are multi-product firms that compete à la Bertrand on the deposit and lending markets. The markets are imperfect, and banks exert market power.

Demand elasticity estimates allow us to recover markups, that we use to infer marginal costs. From the marginal costs, we can then estimate the cost function. We decompose balance sheet costs into regulatory costs and portfolio risk costs. The former are a function of how close the bank is to meeting its regulatory ratios, while the latter take the form of a classic Markowitz (1952) variance-covariance matrix. Given that banks can freely substitute between balance sheet elements adjust the size of their balance sheets, the marginal benefit of assets has to be equal to the marginal cost of liabilities. This equilibrium condition provides a set of moment equations that allows us to recover risk aversion parameters and shadow costs of regulatory constraints for individual banks using simple linear regression techniques.

Our model allows us to compute counterfactual equilibriums under alternative policies. We focus on three policy alternatives: First, we evaluate how much the 4 trillion of central bank reserves resulting from LSAPs crowded out bank lending in equilibrium by computing the equilibirum under lower amount of reserves. Specifically, we identify a maximum lending output around 2 trillions: aggregate bank lending output would have been 5% higher in Q4 2021.

Second, we evaluate what would have been the counterfactual lending output if reserves were excluded from the leverage ratio. Such policy intervention would be easy to implement, and would follow the precedent of leverage ratio relief that was implemented during the COVID crisis. [RESULTS TBD]

Third, we analyze how much a change in Basel III's regulatory requirement for the liquidity coverage ratio, leverage ratio and the net stable funding ratio would impact the bank's balance sheet in equilibrium. [RESULTS TBD]

Related literature: Our work spans several strands of literature in banking and finance. First, we contributes to the novel strand of literature that borrows structural estimation techniques from empirical IO. (S. Berry et al., 1995; S. T. Berry, 1994; McFadden, 1974; Nevo, 2001) to understand competition and frictions in banking. A few recent papers, such as Wang et al. (2022) and Diamond, Jiang, and Ma (2022) study monetary policy in the U.S. via the lens of a structural model and demand systems.[6] Specifically, Wang et al. (2022) examines the relationship between bank market power and the transmission of conventional monetary policy through the response of loan rates to changes in the federal funds rate. They find that banks wielding greater market power tend to be less willing to pass on policy rate adjustments to loan rates. Diamond, Jiang, and Ma (2022) examine unconventional monetary policy transmission and focus on the role of central bank reserves. Their results show that each dollar of reserves reduces bank lending provision by 7.7 cents, which mitigates the expansionary impacts of unconventional monetary policy.

While both aforementioned papers discuss the impact of regulatory frictions in their analysis, our methodology allows us to directly quantify the cost of specific regulatory constraints. Further, the impact of excess reserves on lending provision has not been quantified yet in the European market, where several idiosyncratic elements should theoretically lead to a more negative impact of reserves on economic output. In particular, the Eurozone has no reverse repo facility, which means that reserves cannot leave the banking system. Moreover, the central bank collected negative interest rates on excess reserves, which imposed direct costs on banks' reserve holdings.

[6]These tools have also been applied in the context of retail deposits (Egan, Hortaçsu, & Matvos, 2017)), insurance (Koijen & Yogo, 2016), corporate lending (Crawford, Pavanini, & Schivardi, 2018) mortgages (Benetton, 2021; Buchak et al., 2018, 2024), shadow banks (Xiao, 2021), and digital banking (Koont, 2023).

Second our study relates to the broader body of research that investigates the effects of QE and monetary policy transmission in the Euro-area. For examples of recent work, see e.g. Bottero et al. (2022), Carpinelli and Crosignani (2021), Martins, Batista, and Ferreira-Lopes (2019), Paludkiewicz (2021), and Peydró, Polo, and Sette (2021). As this literature is mostly non-structural, our structural approach complements prior work in that we can provide counterfactual estimates of the effects of these monetary policy tools.

Third our paper connects to the literature on European money markets after the Global Financial Crisis (GFC) (Arrata et al., 2020; Ballensiefen, Ranaldo, & Winterberg, 2023; Bechtel et al., 2021; Eisenschmidt, Ma, & Zhang, 2022; Perignon, Thesmar, & Vuillemey, 2018). We contribute to this strand of literature by showing that the decrease in volume in the unsecured interbank market as well as other money market trends documented in prior works are linked to the increased supply of reserves.

Finally, our paper is connected to quantitative macro-finance literature that tries to evaluate the impact of capital requirements and other regulatory policies. Begenau and Landvoigt (2022) and Corbae and Erasmo (2021) both develop models of the banking system to study the quantitative impact of regulatory policies on bank risk-taking and market structure. De Fiore et al. (2024) emphasize changes in money markets and collateral policies with their model. We contribute to this literature by disentangling the effects of each the main components of Basel III regulation, and analyzing their interactions with unconventional monetary policy. However, we estimate rather than calibrate all the parameters in our model, which makes our approach more empirical in nature.

Roadmap: The remainder of the paper is organized as follows. Section 2 describes the institutional details of unconventional monetary policy in Eurozone, the rise of excess reserves and decline of interbank market, and the Basel III bank regulatory constraints. Section 3 briefly describes the data and provides descriptive statistics. Section 4 provides reduced form evidence of reserves crowding out bank lending using the French credit registry data. Section 5 introduces the structural model and the empirical methodology. Section 6.1 presents the results. Section **??** presents some robustness tests. Section 7 presents the counterfactuals. Section 8 concludes.

2 Institutional details

2.1 Asset purchase programs

Large scale asset purchase (LSAP) programs or "quantitative easing" (QE) is a non-standard monetary policy measure designed to tackle deflationary pressures and stimulate economic growth. The idea is the following: through the purchase of assets on the securities market, central banks should push asset prices up during economic downturns and ensure price stability. Additionally, LSAP should bolster credit through the interest rate channel, especially when the policy rate remains constrained at the zero lower bound: As asset prices rise, interest rates decline, collateral value increases and this stimulates the demand for credit.

While the impact of QE on asset prices is indisputable[7], the real impact of QE on bank lending is debated. The literature estimates are at best small, and often insignificant. When significantly positive estimates are found, the effect of QE seems to be stemming from portfolio or balance-sheet channels rather than from the pure asset price/interest rate channel [8]. Indeed, while LSAPs pushes down interest rates, it starves banks from high-yield investment opportunities. Further, LSAPs increase the supply of reserves, whose impact is ambiguous, and change banks' balance sheet composition. It is therefore difficult to quantify the impact of quantitative easing on lending, and in particular to disentangle these channels. Nonetheless, such disentanglement is necessary if we want to assess the effects of unconventional monetary policy. While a channel might dominate for a given level of asset purchases, another can become dominant in an other setting. Further, these channels can take time to build up: reserves induced by LSAP might start to crowd out lending only once the banks run out of available balance sheet space. As Isabel Schnabel, a Member of the ECB's Executive Board, put it in a May 28, 2024 speech[9], "Even if asset purchases have clearly quantifiable benefits, they also come with side effects. These may be difficult to assess, as they can materialise with considerable delay.". Therefore, careful estimation of the impact of QE on banks' credit provision through a structural model is necessary to address policy outcomes.

2.2 Asset purchase transactions and reserves

An important consequence of LSAP is the increase in the quantity of reserves held on banks' balance sheets. When the central bank buys an asset from a bank, the operation is akin to an asset swap: the bank swaps some of its securities for reserves (see Table 1). Even an assep swap might not be neutral: as pointed out by Christensen and Krogstrup (2017), a slight change in the composition of the bank's asset holdings may have important implications for monetary policy transmission. As the liquidity, duration and yield of their portfolio is changed, banks will rebalance towards their new optimal portfolio of investments.

Alternatively, when the central bank buys an asset from a non-bank entity, as

[7]Although its magnitude is subject to discussion, see Arrata et al. (2020), D'avernas and Vandeweyer (2023), Koijen et al. (2021), Paludkiewicz (2021), and Vayanos and Vila (2023)

[8]See Brunnermeier and Sannikov (2016), Paludkiewicz (2021), and Rodnyansky and Darmouni (n.d.)

[9]ECB Press release 2024

shown in Table 2, the operation expands the balance sheet: both bank reserves and deposits grow. As non-bank entities do not themselves hold reserve accounts at their national central bank, banks have to intermediate the transaction. The intermediary bank credits the seller with a deposit equal to the amount due for the purchased asset, while the central bank credits the intermediary bank with reserves equal to that amount. Therefore, in addition to providing liquidity to the seller with the aim of boosting economic activity, the transaction expands the balance sheet of the intermediary bank.

The one for one increase in reserves resulting from asset purchases led to a tremendous expansion in the quantity of excess reserves[10] – reserves in excess of the minimum requirements – held in the banking system, as illustrated in figure 3.

Central Bank

Securities	Liabilities
Assets	Reserves
IOU	
+ Securities	+ Reserves

Bank

Assets	Liabilities
Securities	Capital
Loans	Deposits
− Securities	
+ Reserves	

Table 1: QE Transaction when a bank is the direct counterparty of the central bank

Roughly 80% of the QE transaction initiated by the ECB were with non-bank counterparties (Rogers, 2022). As highlighted in the cases above, this implies that the allocation of reserves is to a large extent outside of commercial banks' control. Reserves are allocated to banks that take financial corporations operating on the sovereign bond market as clients, and are then spread through the payment system. A core friction is that reserves cannot leave the balance sheet of the aggregate Eurozone banking sector[11].

Central Bank

Assets	Liabilities
Securities	Reserves
IOU	
+ Securities	+ Reserves

Bank

Assets	Liabilities
Securities	Equity
Loans	Deposits
+ Reserves	+ Deposits

Non-Bank

Assets	Liabilities
Securities	Equity
Deposits	Loans
− Securities	
+ Deposits	

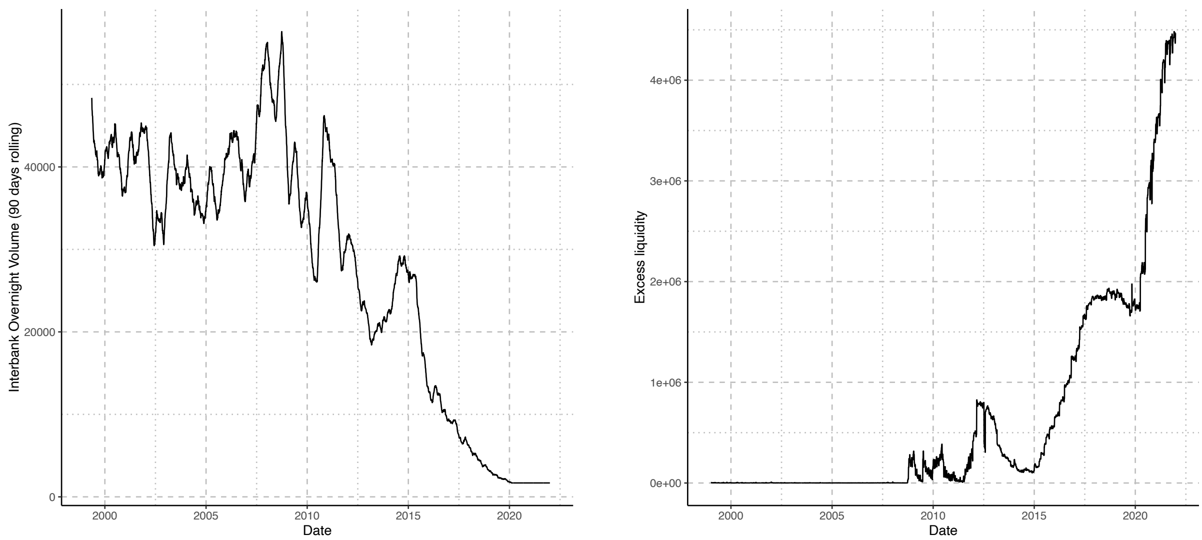
Table 2: QE Transaction when a bank is the intermediary of the counterparty

[10]In Eurosystem jargon, the quantity commonly referred to as excess reserves is labeled as excess liquidity.

[11]An individual bank can theoretically decrease its reserve position through the payment system by issuing loans, keeping its deposits constants, or by decreasing its deposit take-up, keeping assets constants. Since European banks mostly fund their asset positions through the issuance of deposits, actively increasing their assets without issuing deposits or actively reducing their deposit position keeping their asset constants run opposite to the core of their business model.

2.3 Interbank reserves market

There exists ample evidence that the interbank market for excess reserves dried up since the 2008 financial crisis and the implementation of central-bank stimulus. Figure 3 illustrates the evolution of the overnight reserves market volume over time and the quantity of excess liquidity in the system. It appears that the interbank market's size is inversely proportional to the quantity of excess liquidity in the system. One interpretation is that is has become increasingly challenging to lend excess reserves due to the limited availability of potential counterparties. As put by a Bundesbank (2019) report in September 2019: "Lower turnover and a decrease in the spread versus key interest rates reduce the interest income that can be achieved per lending relationship. This leads to a reduction of the supply on the inter-bank money market. In many cases, lower interest income no longer covers the fixed counterparty-specific (monitoring) costs. Consequently, only few institutions are able to lend profitably in the interbank money market, and not all those seeking to obtain central bank reserves on the market will be able to fund themselves at terms commensurate with their respective counterparty risk". We make the opposite argument: the low turnover in the interbank market is in our opinion due to the reserve glut. As banks have an excess of liquid assets and are vastly in excess of the minimum reserve requirements, the demand for central bank reserves drop.



(a) Overnight Reserves Market Volume

(b) Excess Liquidity

Figure 3: The market for reserves

The figure on the left hand side depicts a measure of the overnight interbank market volume, that is the volume of daily transactions between banks taking part in the EONIA panel. The figure on the right hand side depicts the volume of excess liquidity in the European Banking system. As the excesss liquidity peaks, the transacted interbank volume plummets.

The evidence that large scale asset purchases were behind the sharp decline of the interbank money market post-GFC is illustrated in Figure A1. It shows a structural break at the start of monetary easing, as the market switched from the a scarce reserves regime to a market with ample excess reserves. With the implementation of monetary easing, the volume of the overnight interbank market has been reduced to an ever-decreasing fraction of the total excess liquidity in the system.[12] Before monetary easing, the volume of overnight loans on the reserves market was approximately 50 times the quantity of excess reserves. This was because banks had to engage in aggressive trading of reserves to meet their reserve requirements.

While the shift from a **scarce reserves regime** to an **ample reserves regime** by the ECB was potentially a welcomed change for cash starved banks, it may have increased the balance sheet costs and acted as financial burden for liquid banks. It is worth noting that the dislocation of the interbank market goes further than just fewer trades. As the overall quantity of reserves exploded, the overnight rate became higher than the 1-month rate, as Figure 4 illustrates. This highlights a fundamental reversal of the market: banks demand to be paid a spread[13] to borrow reserves. This signals that excess reserves impose a cost on banks: It is not that the banks are unwilling to lend away their reserves, but rather that no bank is willing to borrow reserves without a substantial discount.

2.4 Bank regulation

A key component driving the balance sheet cost of large excess reserves is Basel regulation. The Basel III framework, announced in 2010, was developed by the Basel Committee on Banking Supervision (BCBS) to strengthen the regulation, supervision and risk management of the banking sector. The Basel III regulatory framework imposes several requirements on banks to ensure their stability and resilience. These requirements can be broadly categorized into capital requirements and liquidity requirements.

2.4.1 Capital Requirements

Capital regulations are designed to ensure that banks hold sufficient capital to absorb losses and remain solvent. There are two key capital requirements:

Common Equity Tier 1 Risk-Weighted Capital (CET1) Requirement: The CET1 ratio requires banks with riskier assets to hold more capital. It is defined as follows.

[12] Note that this does not uniquely affect the overnight reserves market as the secured market and the market for longer maturities displays similar patterns.

[13] This means that the asking rate on the interbank market is below the deposit facility rate: a bank that would borrow at this rate could immediatly deposit the reserves on its account at the ECB to make the spread.

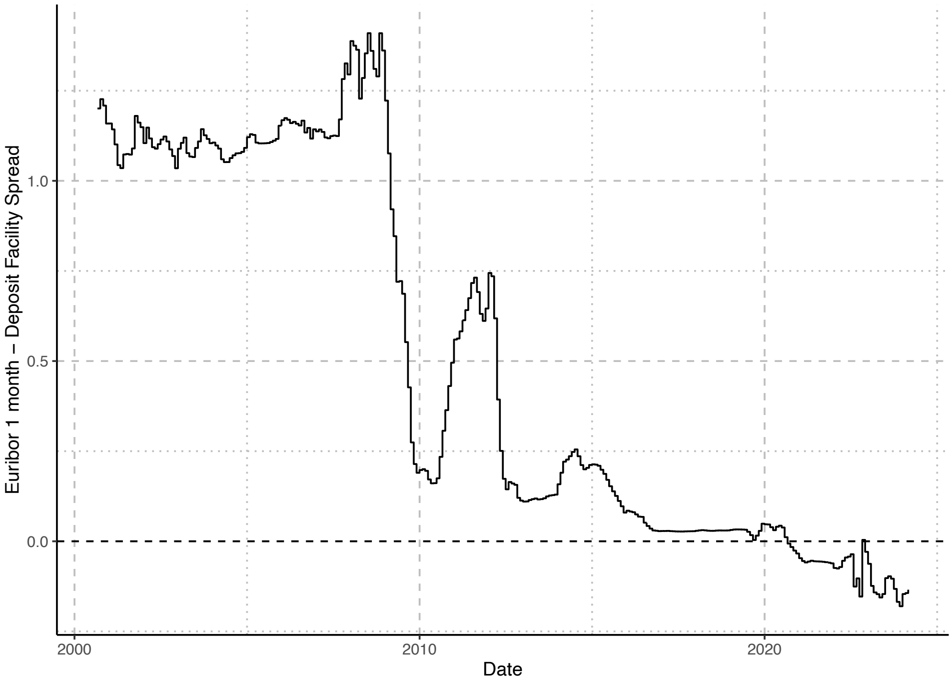


Figure 4: Spread between the 1-month EURIBOR and the Deposit Facility rate

The figure plots the spread between the 1-month interbank rate and the interest rate paid on reserves by the European Central Bank. As the plot illustrates, since late 2020 a bank that manages to borrow at the interbank rate could deposit the reserves on its ECB deposit facility account to make a risk-free return.

$$\text{CET1 Ratio} = \frac{\text{Common Equity Tier 1 Capital}}{\text{Risk-Weighted Assets (RWA)}} > \delta_{\text{CET1}}$$

where

- **Common Equity Tier 1 Capital** includes common stock and retained earnings.
- **Risk-Weighted Assets** (**RWA**) represent the total assets of the bank, weighted by their riskiness; riskier assets receive higher weights.
- δ_{CET1} is the minimum required CET1 ratio, set by regulators.

Leverage Ratio (LEV): The leverage ratio provides a non-risk-based measure to limit the overall size of the bank relative to its capital. It is defined as:

$$\text{LEV} = \frac{\text{Tier 1 Capital}}{\text{Total Exposure}} > \delta_{\text{LEV}}$$

where:

- **Total Exposure** includes all assets recorded on the bank's balance sheet, as well as the net credit risk exposures from off-balance sheet items. Importantly, it includes central bank reserves.

- δ_{LEV} is the minimum required leverage ratio, which may vary between banks. Systemically important banks (G-SIBs) are subject to higher requirements.

Both the CET1 and LEV requirements aim to ensure that banks can absorb substantial losses and remain solvent during periods of financial stress (Cecchetti & Kashyap, 2016).

2.4.2 Liquidity Requirements

In addition to capital adequacy, banks must also meet liquidity requirements to ensure they can meet short-term and long-term obligations.

Liquidity Coverage Ratio (LCR) : The LCR ensures that banks have enough high-quality liquid assets to survive a short-term liquidity stress scenario lasting 30 days. It is defined as:

$$\text{LCR} = \frac{\text{High-Quality Liquid Assets (HQLA)}}{\text{Total Net Cash Outflows over 30 Days}} > \delta_{\text{LCR}}$$

where:

- **High-Quality Liquid Assets (HQLA)** are assets that can be easily and quickly converted into cash with little or no loss of value.
- **Total Net Cash Outflows** represent the expected cash outflows minus inflows during a 30-day stress period.
- δ_{LCR} is the minimum required LCR, set by regulators.

Net Stable Funding Ratio (NSFR): The NSFR promotes resilience over a longer time horizon by requiring banks to maintain a stable funding profile relative to the composition of their assets and off-balance-sheet activities. It is defined as:

$$\text{NSFR} = \frac{\text{Available Stable Funding (ASF)}}{\text{Required Stable Funding (RSF)}} > \delta_{\text{NSFR}}$$

where:

- **Available Stable Funding (ASF)** measures the portion of a bank's capital and liabilities expected to be reliable over the one-year time horizon.
- **Required Stable Funding (RSF)** reflects the volume of assets that could hardly be monetized over a longer stress period of lasting several months. Assets that are less liquid of have longer maturities have higher weights.
- δ_{NSFR} is the minimum required NSFR, set by regulators.

The LCR and NSFR are complementary measures: LCR focuses on short-term liquidity, ensuring banks can meet outflows during acute stress over 30 days, while NSFR addresses longer-term stability, promoting funding structures that reduce the risk of future funding stress over a one-year horizon.

We describe at the end of the next section how we compute the ratios ourselves from available balance sheet data, in line with prior work such as Sundaresan and Xiao (2024) or Hong, Huang, and Wu (2014).

A common characteristic of Basel III regulatory requirements is that they are defined as ratios involving weighted sums of banks' assets and liabilities. This structure lends itself to being modeled as an optimization problem under constraints, as highlighted by Fraisse, Lé, and Thesmar (2020). In our approach, we leverage this characteristic to model the bank's cost function, incorporating the regulatory ratios as constraints that influence banks' portfolio choices.

3 Data

We gather data from three main sources. We obtain aggregate series used for generating illustrative figures and calculating summary statistics from the European Central Bank (ECB) Data Warehouse. This source provides comprehensive macroeconomic and financial data essential for our initial analysis and visualization. For granular French regulatory data, we utilize datasets provided by the Banque de France. We extend our gratitude to the Banque de France for granting us access to their data through the secured CASD data management service[14]. This detailed regulatory information is crucial for accurately modeling the French banking sector and estimating structural parameters. To obtain balance sheet data at the European level, we source information from the Bureau van Dijk BankFocus and Orbis databases. While these datasets are less granular, their extensive coverage across multiple European banks allows us to compute policy counterfactuals for the entire Eurozone.

We describe the data collecting process in detail in the appendix section E, and provide a short summary below.

3.1 Data collection

The Banque de France has provided us with several key regulatory datasets. All datasets are anonymised by the Banque de France, and the last period of observation is Q4 2021.While the starting date for available data differs between dataset, we have chosen to start data collection on Q1 2013 for two main reasons: First, this ensures that

[14]The views expressed herein are those of the authors and do not necessarily reflect those of Banque de France.

we have data points in every single dataset provided by the Banque de France during the whole time period. Second, this start date is just before Basel III regulation was released. At this point in time, the specifics of the regulation were common knowledge, and it seems reasonable to assume that banks were forward-looking enough to start considering Basel III regulation in their decision-making. Such an assumption is crucial for our empirical setup.

Our reduced form analysis is based on Banque de France's credit registry, a quarterly dataset which records any credit exposure to non-financial corporations above 25,000 euros. To reconstruct the detailed balance sheets necessary for our structural estimation, we merge various datasets: quarterly balance sheet data, monthly data on the volumes and rates for different deposits and loans categories for non-financial corporations and households, and detailed securities holdings data. We aggregate the data items into 12 mutually exclusive categories on the asset side and 12 mutually exclusive categories on the liability side to recover a granular balance sheet. We exclude off-balance sheet positions from the analysis. When the bank-level rates are not available[15], we recover market-level rates using ECB data. Additionally, we utilize securities holding statistics to gauge the share of balance sheet expanding QE transactions – where non-banks are the counterparty to the central bank – and find results in line with Rogers (2022). Our counterfactuals are computed using Bureau van Dijk's BankFocus data, that provides aggregated balance sheet data for European banks at the yearly level. To avoid consolidation issues and ensure data quality, we focus on the 152 most important banks in the Eurozone, that we define as any bank that has taken part in European Banking Authority's stress tests between 2014 and 2023.[16]

3.2 Basel III ratios inference

We face three difficulties in observing regulatory ratios: The regulatory ratios are not always publicly available – especially at a quarterly level, the Banque de France data is anonymized and doesn't allow us to match the observed ratios to the banks in our sample [17] , and the CET1 ratio is computed using internal models, which might hamper comparability across banks. Therefore we follow Hong, Huang, and Wu (2014) and Sundaresan and Xiao (2024) and replicate the regulatory ratios using information from publicly available documentation, published regulation, as well European Commission and EBA guidelines. To the best of our knowledge, this paper is the first to

[15]That is, for the items we model the bank as a price-taker.

[16]123 banks took part in the 2014 stress test, while in the latter years the number of banks was generally around 50, at which point they cover about 70% of EU bank assets. The total sample covers around 85% of total bank assets in the Eurozone and include all G-SII and O-SII banks.

[17]While it is theoretically possible to identify individual banks using their total assets, this would violate our data agreement with the Banque de France.

replicate all four Basel III regulatory constraints for the whole European banking sector.

We manually collected the regulatory weights by thoroughly reviewing Basel III documentation. When necessary, we made informed assumptions to map the regulatory weights to our dataset. The assumptions required to compute the ratios are listed in Table A4, and we list the regulatory weights in Tables A5 to A8. Table 3 presents the result of an OLS regression of the true observed ratios (as reported) on our imputed ratios, using the BankFocus data. The high goodness-of-fit and coefficients hovering around 1 vindicates our methodology. When using the French regulatory data, we have access to a more granular decomposition of items which allows us to compute the ratios with improved precision. If anything, we expect our imputed ratios to be closer to reality when using the Banque de France dataset.

Table 3: Regression of reported regulatory ratios on imputed regulatory ratios

	Dependent variable:			
	LCR	NSFR	CET1	LEV
	(1)	(2)	(3)	(4)
imputed LCR ratio	1.016*** (0.033)			
imputed NSF ratio		0.933*** (0.008)		
imputed CET1 ratio			1.089*** (0.020)	
imputed LEV ratio				0.870*** (0.011)
Observations	499	300	714	508
R^2	0.650	0.981	0.804	0.922
Adjusted R^2	0.649	0.981	0.803	0.922
Residual Std. Error	1.313 (df = 498)	0.178 (df = 299)	0.084 (df = 713)	0.019 (df = 507)
F Statistic	923.604***	15,239.820***	2,917.074***	5,980.116***
Note:				*p<0.1; **p<0.05; ***p<0.01

4 Reduced form analysis

In this section, we provide reduced form estimates of the impact of reserves on bank lending. Analysing the impact of reserves immediately faces us with two potential endogeneity issues. Banks that hold significant reserves may serve different clientele compared to those that do not. Specifically, larger banks, which are more likely to hold increased reserves, tend to be affiliated with larger firms. If large firms respond differently to the economic crises that prompted asset purchases, this might muddle our estimates. Second, reserves are issued when monetary policy is at its most expansionary and the economy is at risk of recession. Therefore, it is extremely difficult to gauge whether any change in credit issuance is due to reserves, expansionary monetary policy, or poor economic conditions. To mitigate these endogeneity issues, we adopt a methodology spearheaded by Khwaja and Mian (2008), that compares lending growth across different banks serving the same firm. Firm-year fixed effects neutralize the firm-specific and year-specific variation: the identifying variation that is left must be the bank-specific element.

We can run such a research design because we have data on every single bank-firm relationship in France with principal above 25000. The French credit registry registers information on the firm, the credit, and a bank identifier that we use to match with balance-sheet data. The breadth of the dataset, including more than 100 million observations, allows us to provide robust estimates even though we cancel most of the firm-level variation.

In the remainder of this section, we denote banks by i, firms by j, and time by t. Our dependent variable is the growth rate of credit, which we define in two different ways. The first difference credit growth rate,

$$\text{Credit growth rate (FD)} : Y^{\Delta}_{ijt} = \Delta_{t,t-1} log(\text{Credit Outstanding}_{ijt})$$

measures the change in the credit provided in a specific bank-firm relationship. It requires the bank-firm relationship to exist in both period t and $t-1$ to be computed, and can be thought of as the intensive margin. Therefore, it neglects the creation of new relationships as well as the termination of existing ones.

The mid-point growth rate,

$$\text{Mid-point growth} : Y^{M}_{ijt} = 2 \cdot \frac{\text{Credit Outstanding}_{ijt} - \text{Credit Outstanding}_{ijt-1}}{\text{Credit Outstanding}_{ijt} + \text{Credit Outstanding}_{ijt-1}}$$

measures the average growth over the period by taking the mid-point as the basis for calculation. It has the advantage of accounting for both the extensive and the intensive margins (Davis & Haltiwanger, 1992), as it allows for observations where the credit outstanding is zero at t or $t-1$.

Our main regression equation takes the following form:

$$Y_{ijt} = \alpha Res_{j,t} + \beta Z_{jt} + FE_{it} + \epsilon_{ijt} \tag{4.1}$$

Where $Res_{j,t}$ is a measure of reserves of bank j, Z_{jt} is a vector of bank-level controls, and we add a firm-year fixed effect. Table 4 shows the outcome of a quarter-by-quarter regression of the quarterly growth of credit on the reserves over the 2013-2021 period. These estimates are economically significant. Over the period, the quantity of reserves held on the aggregate bank balance sheet increased twenty-fold between 2015 and 2022. The reserve share peaked around 13% of total bank assets in late 2020, as illustrated in Figure 5. A back-of-the-envelope calculation from the estimates presented in Table 4 hints at a 0.6% reduction in quarterly credit growth under those conditions.

Nonetheless, the regression results presented in Table 4 have several limitations.

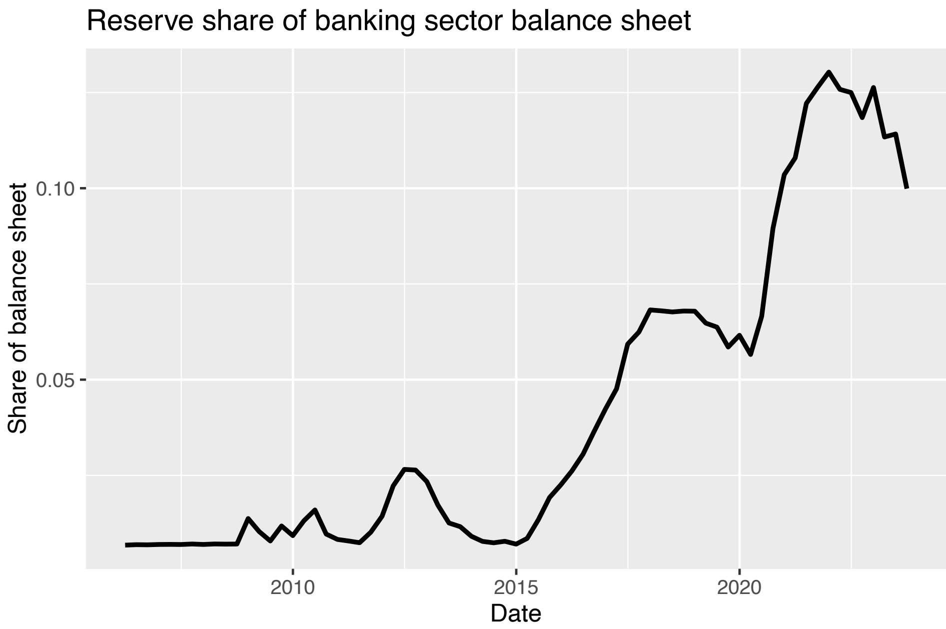


Figure 5: Share of aggregate bank balance sheet occupied by reserves in the Eurozone

First, the impact of an increase in reserves may become more pronounced when reserves are already abundant in the banking system. Second, our quarter-by-quarter estimation methodology kills most of the identifying variation while retaining substantial noise —short run variations in credit are probably poorly correlated with reserves. To address these issues, we split our sample into two periods of interest and run our regression over the whole period. That is, we take the growth rate between the first quarter of the period and the last quarter of the period, ignoring the intermediate observations. The first period of interest is the 2015Q1-2018Q2 QE episode, that saw the continuous purchase of securities by the ECB as a part of its asset purchase programmes. The quantity of reserves in the banking system increased sevenfold during the interval. In 2018, it was decided that the net bond purchases would wind down and then stop. The bonds would be ultimately left to mature after a maintenance period, during which the net purchases—and therefore the net reserve injections—were set to be zero. However, before the end of the maintenance period, two crises hit the financial system. The September 2019 repo crisis and the COVID-19 pandemic from March 2020 onwards led to a resumption of net purchases, that led to a skyrocketing of excess liquidity from 1.5 trillion euros to more than 4.5 trillion euros at its October 2022 peak. As our dataset ends in late 2021, the second period of interest is defined as 2019Q4-2021Q4.

The regression results presented in Table 5 fail to reject the null hypothesis of no effect of reserves on lending during the 20152018 QE episode. In contrast, the results presented in Table 6 strongly reject the null in the period 2019-2021: reserves negatively impacted lending. This suggests that reserves were not hindering lending at

Dependent Variables:	Growth rate (FD)		Mid-point growth	
Variables				
Reserve Share$_{t-1}$	-0.0186		-0.0536**	
	(0.0226)		(0.0244)	
Δ Reserves		-0.0009***		-0.0019**
		(0.0003)		(0.0010)
Total Assets$_{t-1}$	0.0009	0.0012**	0.0019	0.0011
	(0.0007)	(0.0005)	(0.0014)	(0.0012)
Firm-Year FE	Yes	Yes	Yes	Yes
Observations	21,021,804	20,478,873	24,649,298	23,999,864
R^2	0.55494	0.56203	0.78650	0.79336
Within R^2	1.92×10^{-5}	4.43×10^{-5}	4.22×10^{-5}	3.51×10^{-5}

Clustered at the bank-level standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 4: Quarterly credit growth: Intensive vs extensive margin regressions

Period: 2013-2021.
Reserve Share measures the share of assets that is occupied by reserves at the end of the quarter. Δ Reserves measures the growth in reserves from quarter $t-1$ to quarter t. Total Assets are the log total assets of the lending bank.

first, which is in line with early reports on the effect of large excess reserves on lending (Kandrac, Kokas, & Kontonikas, 2021; Kashyap & Stein, 2012; Martin et al., 2019). Remember that the estimation setup ensures that only the relative differences between banks matter. In other words, we cannot attribute the difference in estimates to the different economic climate.

A back of the envelope calculation[18] suggests that the loss in credit provision due to the 3 trillion euro increase in reserves in 20202021 could be between 10% and 15% of aggregate credit. This represents 500 to 750 billion euros of missing loans for non-financial corporations alone. However, this estimate likely represents an upper bound: the locally linear nature of the regression, combined with potential equilibrium effects[19], means we may be be overestimating the actual equilibrium impact.

There is however a concern over the endogeneity of reserves. While reduced-form evidence is indicative that reserves crowd out loans, it could also be that banks with little lending capacity are more likely to willingly take up reserves as a kind of substitute investment. Indeed, since reserves are riskless assets and thus excluded from

[18]Namely, taking the increase in reserve share over the period and multiplying it by the estimated coefficient on reserve share.
[19]That is, while large reserves banks might reduce lending, small reserves banks might increase lending.

Dpdt Variables:	Growth rate (FD)			Mid-point growth (DH)		
Variables						
ResShare_{t-1}	-0.1762			-0.1316		
	(0.5348)			(0.2664)		
Δ Reserves		0.0066			-0.0002	
		(0.0224)			(0.0118)	
MidResShare			-0.7178			-0.4637
			(0.5566)			(0.3003)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	523,681	482,947	483,256	578,294	534,319	534,658
R^2	0.75608	0.78616	0.78622	0.70717	0.72875	0.72875
Within R^2	0.00328	0.00023	0.00055	0.00143	2.18×10^{-6}	0.00038

Clustered at the bank-level standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 5: 2015Q1-2018Q2 Event Study

Period: The dependent variable is the observed growth rate of credit between 2015Q1 and 2018Q2. Reserve Share measures the share of assets that is occupied by reserves at the end of the quarter. Δ Reserves measures the growth in reserves from quarter $t-1$ to quarter t. ResShare_{t-1} denotes the reserve share at the beginning of the period. MidResShare denotes the midpoint of the reserve share of the balance sheet between the end-of-period share and the beginning-of-period share.

stable funding requirements, they provide liquid coverage for cash outflows and generally decrease the risk of the bank's portfolio. Table 8 describes a regression where we instrument for the growth of reserves using the share of the balance sheet occupied by financial clientele in the first quarter of 2014. As highlighted in Section 2, banks that have financial institutions as clients are exposed to quasi-exogenous[20] increases in the quantity of reserves held on their balance-sheet. Refusing a transaction from one of these clients could strain the banking relationship, which makes it unlikely that banks actively manage the transactions of the financial institutions they serve. As such, the instruments are plausibly exogenous. The instrument is plausibly exogenous, since first of the series of quantitative easing announcement by the ECB happened in October 2014. The validity of using financial clientele as an instrument is highlighted in Table 7. Financial clientele is a strong predictor of the quantity of reserves on the balance sheet, and the coefficients behave as expected: financial clientele overall increases the quantity of reserves, but an exposure more tilted towards financial loans leads to lower relative reserves. This is because the funds obtained through loans can be used by clients to make payments, which are then settled with other banks using reserves. Importantly, the IV regressions coefficients in Table 8 are larger than those in the OLS

[20] See Table 2.

Dpdt Variables:	Growth rate (FD)			Davis-Haltiwanger (DH)		
Variables						
ResShare_{t-1}	-1.603			-0.6655		
	(1.060)			(0.4054)		
Δ Reserves		-0.0462***			-0.0268***	
		(0.0122)			(0.0067)	
MidResShare			-2.023**			-0.8551**
			(0.9222)			(0.3614)
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics						
Observations	553,157	482,690	483,249	595,401	519,213	519,816
R^2	0.76455	0.77420	0.77498	0.71906	0.73521	0.73492
Within R^2	0.00596	0.00791	0.01166	0.00412	0.00794	0.00716

Clustered at the bank-level standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 6: 2019Q4-2021Q4 Event Study

Period: The dependent variable is the observed growth rate of credit between 2019Q4 and 2021Q4, the most recent bout of QE.
Reserve Share measures the share of assets that is occupied by reserves at the end of the quarter. Δ Reserves measures the growth in reserves from quarter $t-1$ to quarter t. ResShare_{t-1} denotes the reserve share at the beginning of the period. MidResShare denotes the midpoint of the reserve share of the balance sheet between the end-of-period share and the beginning-of-period share.

Dependent Variables:	Reserve Share$_{t-1}$	Δ Reserve Share	Δ Reserves
Model:	(1)	(2)	(3)
Variables			
Financial Loans	-0.8653***	-0.3124***	-22.50***
	(0.0564)	(0.0525)	(2.225)
Financial Deposits	0.4586***	-0.0774***	2.656***
	(0.0806)	(0.0194)	(0.7086)
FinL$\times$ FinD	40.60***	39.37***	1,245.0***
	(3.276)	(2.645)	(111.5)
Fit statistics			
Observations	400	400	400
R^2	0.53425	0.49504	0.57812
Within R^2	0.26445	0.18959	0.06002

Table 7: IV First Stage

This table describes the first-stage of the IV estimation.
Reserve Share$_{t-1}$ denotes the share of assets occupied by reserves in 2019Q4. Δ Reserve Share measures the difference in the share of the balance sheet occupied by reserves in 2021Q4 and the share of the balance sheet occupied by reserves un 2019 Q4. Δ Reserves denote the growth rate of reserves on the balance sheet of the bank between 2019Q4 and 2021Q4. Financial loans (deposits) refers to the share of the balance sheet occupied by loans to (deposits by) financial corporations in 2014Q1. As QE was announced later in 2014, these variables are plausibly exogenous.

regressions, which implies that—if anything—ignoring the potential endogeneity of central bank reserves leads to a downward bias in point estimates.

Now that we have established a plausibly causal impact of reserves on lending, we present the main contribution of our paper: the structural model and associated quantification exercise of the equilibrium effects of reserves.

5 Model

Our model is in essence a Monti-Klein model of the banking industry. Banks optimize their portfolio of investments to maximize their returns and get funded through liabilities. We model the borrowers' demand for loans and deposits as imperfect markets with horizontally differentiated products[21], where banks compete in different markets for different type of borrowers. In other words, we consider that loans to firms and loans to households are separated markets. Banks are multi-product firms[22]: For instance, they potentially offer both demand deposits and time deposits to their customers on the same market. There are three important frictions in the model. First, the

[21] See (S. Berry et al., 1995) for a seminal example

[22] See Nevo (2001) for a seminal discussion of demand market equilibrium with multi-product firms.

Dependent Variables:	Credit growth (FD)		Mid-point growth	
Model:	Base	IV	Base	IV
Variables				
Reserve Share_{t-1}	-0.8374	-2.675*	-0.3021	-1.454*
	(0.6504)	(1.385)	(0.2238)	(0.7651)
Δ Reserve Share	-2.443***	-5.618*	-1.472***	-3.382**
	(0.4404)	(2.885)	(0.2112)	(1.536)
Total Assets_{t-1}	0.1472***	0.2210***	0.0846***	0.1293***
	(0.0208)	(0.0561)	(0.0107)	(0.0300)
Firm fixed-effects	Yes	Yes	Yes	Yes
Fit statistics				
Observations	807,218	807,218	866,202	866,202
R^2	0.68241	0.67726	0.64582	0.63881
Within R^2	0.01749		0.01965	
IV tests				
Wu-Hausman	/	185.2	/	244.7

Clustered at the bank level standard-errors in parentheses

Table 8: 2019Q4-2021Q4 IV Regression

Reserve Share measures the share of assets that is occupied by reserves at the end of the quarter. Δ Reserve Share measures the difference in the share of the balance sheet occupied by reserves in 2021Q4 and the share of the balance sheet occupied by reserves un 2019 Q4. Total Assets are the log total assets of the lending bank in 2019Q4.

bank must fund its asset through liabilities: The balance sheet must clear. Second, the bank faces regulatory constraints, which induce shadow costs when they are binding. Third, the bank's equity is fixed, as we consider that a bank cannot adjust its equity on the short run.

5.1 Conceptual framework: Monti-Klein under constraints

A bank i is endowed with equity E_i and with different types of liabilities stacked in the vector $\mathbf{X}_{i,L}$ with dimensions $J_L \times 1$ where J_L is the number of liability categories. Liabilities include different types of depositssuch as demand and time depositsas well as wholesale funding sources like certificate of deposits and interbank loans These liabilities pay interest rate which are stacked in the vector $\mathbf{R}_{i,L}$. Similarly, on the asset side, the bank can engage in lending or investing in different types of securities. The vector $\mathbf{X}_{i,A}$ of dimension $J_A \times 1$ includes investment items such as corporate loans, mortgages, bonds, and stocks, with interest rates in $\mathbf{R}_{i,A}$. The specific items included in $\mathbf{X}_{i,A}$ and $\mathbf{X}_{i,L}$ are detailed in Appendix E. In addition to equity, each bank i holds an endowment of reserves $Q_{i,R}$, which can be traded on the interbank market. The amount of reserves after trading on bank i's balance sheet is given as $Q_{iR} + \Delta Q_R = \hat{Q}_{i,R}$, which may be higher or lower than the initial allocation depending the sign of the traded amount $\Delta Q_{i,R}$. Naturally, across all banks i, $\sum_i \Delta Q_{i,R} = 0$. The bank has mean-variance preferences with a risk aversion $\frac{\gamma_i}{E_i}$ that is inversely proportional to its equity endowment.[23] Consequently, banks aim to maximize their expected profits—accounting for risk.

Second, a bank also subject to various regulatory and investment constraints that it needs to satisfy. The regulatory constraints we incorporate into the model are the net-stable funding ratio (NSFR), liquidity coverage ratio (LCR), risk-weighted capital ratio, which we refer to as common equity tier equity 1 ratio (CET1), and standard leverage ratio (LEV). These regulatory requirements were introduced in Section 2. We denote regulatory weights in regulatory ratio k as $\boldsymbol{\omega}_k$. When it is necessary to distinguish between regulatory weights on the asset and liability side of the balance sheet, we denote $\omega_{A,k}$ the vector of regulatory weights on the asset side, and $\omega_{L,k}$ the weights on the liability side. [24] A bank must meet the balance sheet equality constraint – assets are equal to liabilities. In addition, we assume that a bank can only take long positions on its asset side, so balance sheet items need to satisfy non-negativity constraints. We also impose a zero lower bound on deposit rates, which leads to a positive amount of

[23]Scaling by bank's equity (i.e net wealth) eliminates the yields an interpretation of γ_i as the constant relative risk aversion coefficient (CRRA).

[24]Naturally, not all items get assigned a positive weight in Basel III regulation. E.g. equity gets a zero weight with current LCR regulation so $\omega_{E,LCR} = 0$. These zero weights simplify the number of items we need to keep track of.

deposits in a discrete choice framework[25]

Third, trading reserves in the interbank market is costly. We model these adjustment costs by assuming that transacting $|\Delta Q_{i,R}|$ dollars of reserves costs each counter party $\tau_{i,R}(\Delta Q_{i,R}) > 0$ dollars where the cost per dollar transacted may itself be a function of transacted amount. We fix notation and take that $\Delta Q_{i,R} > 0$ denotes borrowing on the interbank market. We follow the literature (Dell'Ariccia, Laeven, & Marquez, 2014; Gârleanu & Pedersen, 2013) and assume quadratic transaction costs where $\tau_{i,R}(\Delta Q_{i,R}) = \frac{1}{2}\frac{\varphi}{E_i}\Delta Q^2_{i,R}$. φ is a parameter —common to all banks—that measures the overall cost of trading in the interbank market and this parameter is scaled by bank size as measured by its equity endowment E_i.[26] We assume reserves in the interbank market and ECB deposit facility are risk-free with interest rate of R_{ITB} (interbank rate) and R_{DF} (deposit facility) respectively.

Given this setup, the bank's optimization problem is the following:

$$
\begin{aligned}
\max_{\Delta Q_{i,R}, \mathbf{X}_{i,A}, \mathbf{L}_i} \quad & \mathbf{X}'_{i,A}\mathbf{R}_{i,A} - \mathbf{X}'_{i,L}\mathbf{R}_{i,L} + Q_i R_{DF} - \Delta Q_i(R_{ITB} - R_{DF}) - \frac{1}{2}\frac{\varphi}{E_i}\Delta Q^2_{i,R} - \frac{1}{2}\frac{\gamma_i}{E_i}\mathbf{X}'_i\boldsymbol{\Sigma}\mathbf{X}_i \\
s.t \quad & \mathbf{X}'_{i,A}\boldsymbol{\omega}_{CET1} \leq E_i \\
& \omega_{LEV}(\mathbf{X}'_{i,A}\mathbf{1} + Q_i + 1_{\Delta Q_{i,R}>0}\Delta Q_{i,R}) \leq E_i \\
& Q_{i,R}\omega_{R,NSF} + \mathbf{X}'_{i,A}\boldsymbol{\omega}_{NSF} \leq \omega_{E,NSF}E_i + \mathbf{X}'_{i,L}\omega_{L,NSF} \\
& \omega_{E,LCR}E_i + \mathbf{X}'_{i,L}\omega_{L,LCR} \leq Q_i\omega_{R1,LCR} + \Delta Q_{i,R}\omega_{R2,LCR} + \mathbf{X}'_{i,A}\boldsymbol{\omega}_{LCR} \\
& Q_{i,R} + \mathbf{X}'_{i,A}\mathbf{1} = E_i + \mathbf{X}'_{i,L}\mathbf{1}
\end{aligned}
$$

Here $\mathbf{X}_i = [\mathbf{A}'_i, \Delta Q_{i,R} + Q_{i,R}, -\mathbf{X}'_{i,L}]'$ is a $(J_A + J_L + 1)$-length vector of balance sheet items while $\boldsymbol{\Sigma}$ is a variance-covariance matrix of dimensions $(J_A + J_L + 1) \times (J_A + J_L + 1)$. Note that elements associated with risk-free assets enter this matrix as zeros[27] The regulatory constraint weighs each balance sheet item with their respective regulatory weight.[28]

[25]If depositors prefer to hold their deposits at the bank even when it sets zero deposit rates, then a bank has limited power to push depositors away and faces a positive lower bound on its deposits.

[26]While we introduce this scaling to simplify the model solution by allowing us to write the optimal portfolio weights as multiples of equity, it is also a realistic feature of interbank market. Indeed, without it would be as costly for a small bank to trade, say 1 billion, in the interbank market than it would for a large bank to trade that same amount. In reality, large banks –owing to their size– have a larger network of bank contacts and usual counterparties in the money market, reducing their marginal cost of trading reserves compared to smaller banks

[27]In practice, this is achieved by treating the rows and columns for deposit items as zero. However, we assume that other types of external financing expose banks to convex costs, consistent with the literature (Wang et al., 2022).

[28]Note that traded reserves $\Delta Q_{i,R}$ impact the LCR constraint on both sides of the balance sheet. We simplify this by combining the risk weights of both sides of the balance sheet for traded reserves as $\omega_{R,LCR} = \omega_{R,A,LCR} - \omega_{R,L,LCR}$, a number that is positive and depend on the maturity distribution of interbank loans.

Let us note that $\omega_{E,NSF} = \omega_{R1,LCR} = 1$ and that $\omega_{E,LCR} = \omega_{R,NSF} = 0$, then we can express the cost function as One could then proceed to solve this optimization problem for different optima using standard methods. We do solve a simplified version of this model in section A. In the next section we present an alternative, more empirically grounded, maximization problem that is still in the spirit of this theoretical formulation. This alternative unconstrained optimization problem will then serve as the our baseline to estimate the supply side.

5.2 Supply-side (Banks)

We generalize the optimization problem by allowing for soft constraints. While in theory regulatory requirements can be seen as a maximisation under constraints problem, regulatory ratios are unlikely to exactly bind in practice. Further, the all or nothing nature of shadow costs is questionable: markets and regulators alike punish banks that get close to the minimum ratios. Stress tests require banks to have a suitable buffer, and investors will shy away from banks that look riskier than their counterparts. On the other hand, not meeting a given ratio is not an immediate death sentence. Indeed, a substantial share of banks fails to meet some of its regulatory requirements. Another way to rationalize soft constraints is the the context of a dynamic problem: if a bank has to stay above a minimum requirement and face exogenous, unpredictable shocks each period, it will internalize the costs of staying too close to the minimum and will try to maintain an optimal buffer. Thus, we model regulatory costs Λ as a decreasing function of how comfortably a bank exceeds its regulatory ratios. In We consider that banks internalize the cost of the constraints and adjust their portfolio of assets and liabilities accordingly. By observing banks' portfolios and known regulatory weights, we can infer the shadow costs associated with the different regulatory constraints.
Banks face the following problem:

$$
\begin{aligned}
\max_{\mathbf{X}_{i,A},\mathbf{X}_{i,L},\Delta Q_{i,R}} \quad & \underbrace{\mathbf{X}'_{i,A}\mathbf{R}_{i,A} - \mathbf{X}'_{i,L}\mathbf{R}_{i,L} - \Delta Q_{i,R}(R_{ITB} - R_{DF})}_{\text{Net return on balance sheet positions}} - \mathcal{C}_i(\Delta Q_{i,R}, \mathbf{X}_{i,A}, \mathbf{L}_i) \\
s.t. \quad & \underbrace{\mathbf{1}'\mathbf{X}_{i,A} + \hat{Q}_{i,R} = \mathbf{1}'\mathbf{X}_{i,L} + E_i}_{\text{Assets = Liabilities}} \\
with \quad & \mathcal{C}_i(\tilde{Q}_{i,R}, \mathbf{X}_i) = \underbrace{\frac{1}{2}\frac{\varphi}{E_i}\tilde{Q}^2_{i,R}}_{\text{Trading cost}} + \underbrace{\frac{1}{2}\frac{\gamma}{E_i}\mathbf{X}'_i\boldsymbol{\Sigma}\mathbf{X}_i}_{\text{Risk}} + \underbrace{\sum_k \lambda_{ik}\boldsymbol{\omega}'_{X,k}\mathbf{X}_i}_{\text{Shadow cost of regulation}}
\end{aligned}
$$

Although not explicitly written, $\lambda_{i,k}$ are allowed to be a smooth function of $\mathbf{X}_i$; that is $\lambda_{i,k} = \boldsymbol{\lambda}_k(\mathbf{X}_i)$ while the interest rates for some asset and liability items are allowed to be functions of their respective quantities; $\mathbf{R}_{i,A} = \mathbf{R}_{i,A}(\mathbf{X}_{i,A})$, $\mathbf{R}_{i,L} = \mathbf{R}_{i,L}(\mathbf{X}_{i,L})$—a dependence that comes from the demand side of the model. Note that we need to flip the sign of shadow costs for the LCR constraint to ensure comparability between assets and liabilities, that is $\boldsymbol{\lambda}_i = [\lambda_{CET1,i}, \lambda_{LEV,i}, \lambda_{NSF,i}, -\lambda_{LCR,i}]'$.

As the balance sheet constraint is by definition exactly binding, this yields 2 sets of first-order conditions. Let us denote as $\mathcal{J}$ the set of all balance sheet items, and let us denote the position of bank i in item j at time t as X_{ijt}. The first set of first order conditions drives the allocation of assets barring reserves and boils down to one equation. The second first order condition drives the optimal quantity of reserves[29].

$$R_i(X_{ijt}) + R_i'(X_{ijt})X_{ijt} = \frac{\gamma_i}{E_i}\sum_{m\in\mathcal{J}}\sigma_{jm}\underline{x}_{im} + \sum_k(\lambda_{ikt} + X_{ijt}\frac{\partial\lambda_{ikt}}{\partial X_{ijt}})\omega_{jk} + \lambda_{BS,i} \qquad \text{F.O.C. General} \tag{5.2}$$

$$R_{DF} - R_{ITB} = \frac{\varphi}{E_i}\Delta Q_{ir} + \frac{\gamma_i}{E_i}\sum_{m\in\mathcal{J}}\sigma_{Rm}\underline{x}_{im} + \sum_k(\lambda_{ikt} + \Delta Q_{iRt}\frac{\partial\lambda_{ikt}}{\partial\Delta Q_{iRt}})\omega_{Rk} \qquad \text{F.O.C. Reserves} \tag{5.3}$$

The balance-sheet cost λ_{BS_i} can be thought of as the cost of space on the balance sheet, or as the cost of issuing equity on the long run. It ties the returns of assets to the cost of funding of the bank. This quantity ensure that the bank sits at the optimum: it cannot improve its position by substituting one asset for another, or by issuing liabilities to fund assets. The marginal cost of funding through any liability must be equal to the marginal risk/regulation-adjusted returns on any asset.

5.2.1 Estimation Strategy

To estimate the parameters in Equations (5.2) and (5.3), we utilize the observed data to compute and the demand side estimation we present in the enxt section to compute the left-hand side (LHS) of these equations, that we denote as y_{ijt}. We estimate parameters for Equations (5.2) and (5.3) by stacking up all first-order conditions for each quarter and using stacked panel regression. The estimation involves regressing y_{ijt} on observable variables derived from the right-hand side (RHS) of the FOCs. Given the right parametrization, the RHS is indeed linear unobservables. For instance, the first term involving risk, $\frac{\gamma_i}{E_i}\sum_{m\in\mathcal{J}}\sigma_{jm}x_{im}$, can be decomposed as $\gamma_i \times Risk_{ijt}$, where

$$Risk_{ijt} = \frac{1}{E_i}\sum_{m\in\mathcal{J}}\sigma_{jm}x_{im}$$

is entirely observable.

[29]Note that trading reserves doesn't change the size of the balance sheet when lending, and acts on either side of the balance sheet when borrowing. As such, $\lambda_{BS,i}$ cancels out in the FOC.

Parametrization of the shadow costs: we chose to parametrize the shadow costs as

$$\lambda_{ikt} = \bar{\lambda}_k e^{(1-Ratio_{ikt})} \tag{5.4}$$

In this setup, $\lambda_{i,k}$ are parameterized based on how close banks are to meeting their regulatory requirements. We rescale the ratios such that when a ratio equals one, it matches the minimum regulatory requirement, so $\bar{\lambda}_k$ can be interpreted as the shadow cost when a bank exactly fulfills requirement k. The cost of the constraint exponentially increases (decreases) when the bank violates (is in excess) of the minimum requirement. As explained above, such parametrization intuitively maps into a setting where banks prefer to hold buffers, and where the violation of a constraint is not an immediate threat to the bank's survival. Banks can choose to breach a regulatory requirement if it would be exceedingly costly to meet.
We can rewrite our estimation equation as

$$y_{ijt} = \frac{\gamma}{E_i} \sum_{m \in \mathcal{J}} \sigma_{jm} \underline{x}_{im} + \sum_k \bar{\lambda}_k e^{(1-\text{Ratio}_{ikt})} (1 - X_{ijt} \frac{\partial \text{Ratio}_{ikt}}{\partial X_{ijt}}) \omega_{jk} + \lambda_{BS,i} + u_{ijt} \tag{5.5}$$

where X_{ijt} refer to the euro value of that balance sheet item j. Similarly knowing Ratio_{ikt}, it is easy to calculate $\frac{\partial \text{Ratio}_{ikt}}{\partial X_{ijt}}$. We present these partial derivatives for different regulations and balance sheet items in Section B.
Let's denote

- $RegWeight_{ikjt} = e^{(1-\text{Ratio}_{ik})}(1 - X_{ijt} \frac{\partial \text{Ratio}_{ikt}}{\partial X_{ijt}}) \omega_{jk}$
- $Risk_{ijt} = \frac{1}{E_i} \sum_{m \in \mathcal{J}} \sigma_{jm} x_{im}$

Our regression equation then simplifies to

$$y_{ijt} = \gamma Risk_{ijt} + \sum_k \bar{\lambda}_k RegWeight_{ikjt} + \lambda_{BS,i} + u_{ijt} \tag{5.6}$$

Estimation proceeds with pooled weighted FE regression. Weights are the square root of the size (total assets) of individual banks. $\lambda_{BS,i}$ is treated as a fixed effect for bank i.

5.3 Demand-side (Borrowers and depositors)

We model the firm and household side of the market using a combination of logit demand system and BLP-estimation (S. Berry et al., 1995). Specifically, consumers and firms $j \in \mathcal{J}$ face a discrete choice problem and will choose the option $i \in \mathcal{I}$ that maximises their utility u_{ij}. The optimal choice is described by the indicator function that takes the following value for $i \in \mathcal{I}$:

$$i := \mathbb{1}\{u_{ij} > u_{kj} \; \forall k \in \mathcal{I}\}$$

Generally, we can model the utility in a linear form:

$$u_{ij} = \alpha_j r_i + \beta a_i + \delta_{i,A} + \epsilon_{ij}$$

where α_j denotes the individual-specific coefficients on the good characteristics r_i, β represents the general coefficients on good characteristics x_i, $\delta_{i,A}$ is a good-specific intercept parameter representing unobserved utility and ϵ_{ij} denotes the error term.

As shown in S. T. Berry (1994) and in McFadden (1974), when the distribution of ϵ_{ij} is double exponential[30]this simplifies to a market share equation defining the share of good i in the market

$$S_i = \int_{\mathcal{J}} \frac{\exp(\alpha_j r_i + \beta a_i + \delta_i)}{\sum_{k \in \mathcal{I}} \exp(\alpha_j r_k + \beta a_k + \delta_k)}$$

5.3.1 Market Size

To run the estimation, we need the market size, which determines the share of the outside option $S_{0,nt}$. We recover the market sizes from observed data. We can observe the share of deposits held by non-financial corporations and households held at non-banks using the Securities Holdings Statistics database, which we take as the outside options for the deposits markets. We can recover the amount of borrowing of non-financial corporations at non-banks in a similar manner. Finally, we take the rolling 2-year share of rejected applications for housing loans as the outside option for mortgages, and the (quarterly) share of rejected application for consumer loans as the outside option for consumer lending. Both of these series are made available publicly by the ECB. We sum the two values to get the outside option for household lending.

5.3.2 Estimation Strategy

We run instrumental variable regression to estimate the demand paremeters, as in Diamond, Jiang, and Ma (2022) or Albertazzi et al. (2022). Indeed, we face a clear endogeneity issue when estimating demand, which stems from correlation between bank rates and the residual that represents unobserved demand shocks. A bank that faces a positive demand shock could charge higher rates. This manifests through biased estimates of the elasticity of demand w.r.t. interest rates. As such, estimation relies primarily on careful instrumentation. We document the instruments in the results section.

[30] Or Gumbel extreme value, that is $F(\epsilon) = e^{-e^{-\epsilon}}$

	Elasticity	Instruments	Controls	Observations
HH Lending: Mortgages	-0.1738^{***}	GIV,	Number of Branches,	6,922
HH Lending: ST	-0.31^{*}	Hausman	Equity funding share	
NFC Lending: Mortgages	-1.33^{***}	GIV,	Number of Branches,	8,469
NFC Lending: ST	-1.20^{***}	Hausman	Equity funding share	
NFC Lending: LT	-1.71^{***}			
HH deposits: Demand	24.43^{***}	GIV,	Total Assets,	
HH deposits: Time	1.13^{***}	Hausman	Nation-wide bank,	4,530
			Equity funding share	
NFC Deposits: Demand	7.91^{*}	GIV,	Number of Branches	5,178
NFC Deposits: Time	0.94^{o}	Hausman	Equity funding share	

Table 9: Demand estimates

This table presents the results for demand estimation when the elasticity to interest rates within one market is taken as homogenous. All rates are instrumented using Hausman instruments and granular instrumental variables. Estimates are directly provided in percentage points, that is they reflect the elasticity w.r.t. to a 100bp change in the interest rate. Driscoll and Kray standard errors.

6 Results

6.1 Demand

We estimate the results for the demand side using the Banque de France dataset. We compute the elasticity parameters through instrumental variable regression, using a combination of granular instrumental variables (Gabaix & Koijen, 2024) and Hausman instruments (computed from the sum of the value of assets of competitors as well as the sum of the branches open by competitors). The logic for Hausman instruments is simple: Our Hausman instruments are the weighted average rates charged by the bank on the 3 other markets. That is, when estimating demand for household loans, the instruments are computed using non-financial corporation loans, as well as household deposits and non-financial corporation deposits. The algorithm to compute granular instrumental variables is described in appendix C.

Table 9 show our estimates at a glance. They are in line with the literature (Albertazzi et al., 2022; Diamond, Jiang, & Ma, 2022; Koont, 2023; Wang et al., 2022): A 10 bp increase in the interest rate on household deposits leads to a 2.4% increase in market share, while a 10bp decrease in the interest rate charged on mortgages leads to a 0.017% increase in market share.

6.2 Supply

Procedure Once we have recovered the markups using the demand elasticity estimates, we need to complement our dataset so that every single balance-sheet item has an associated rate. We take the interest rate for the central bank reserves to be the ECB deposit facility rate, we approximate the government securities rate as the 5-year government bond yield on 19-Euro Area countries (FRED ticker IRLTLT01EZM156N), Treasuries as the 6 months Bund yield, long-term wholesale funding and other liabilities as the yield of ICE BofA Euro Financials Corporate Bond Index (LSEG ticker .MEREB00), and other assets the yield of iBoxx Euro Corporates Bond index (LSEG ticker IBBEU003D). We weight the regression using the square root of total assets of the bank.

Cost function estimates: Column 1 of table 10 presents the results of our main specification. The balance sheet constraints are all positive, which is in line with a generalization of optimization under constraints.

The second and third column present estimates obtained separately on sub-samples of assets and liabilities. If our model accurately captures the regulatory-induced costs, the first-order conditions should yield structural parameter estimates that are consistent in both magnitude and direction across these distinct sub-samples. The estimates should be of comparable magnitude and direction, even though we estimate them on these drastically different samples. Empirically, we observe that the estimates derived from assets and liabilities sub-samples are remarkably similar[31]. Given that the regulatory weights differ substantially between assets and liabilities, and considering that banks charge interest rates on assets while paying rates on liabilities, this indicates that our estimates are reliable. Finally, we estimate the model allowing for heterogeneous risk aversion coefficients γ_i. Estimates and goodness-of-fit are comparable to the main specification.[32]

It is important to note that the relative magnitudes of these estimates are not directly comparable. The $\bar{\lambda}_k$ are scaled by regulatory weights and a non-linear function dependent on the distance to the minimum requirement. Therefore, the net stable funding constraint might be costlier to banks on average as the regulatory weights for the NSF are usually larger than the regulatory weights for the leverage constraint. We set out to explore this question in the next section.

[31] Note that the leverage ratio doesn't enter the liability side due to the way it is computed

[32] We also ran several specifications including the risk weighted-asset CET1 ratio, and did not obtain significant results after 2016. We chose to exclude it from the main signification as its mechanically high correlation with the leverage ratio led to a contamination of $\bar{\lambda}_{LEV}$ when $\bar{\lambda}_{CET1}$ is poorly identified.

Dependent Variable:		y_{ijt}		
Estimation:	Main specification	Assets only	Liabilities only	γ_i
Variables				
Risk	**0.1393**	0.4805	-0.0433	
	(0.0948)	(0.2909)	(0.0948)	
$\bar{\lambda}_{LCR}$	**1.864*****	2.807***	3.084***	1.824***
	(0.3683)	(0.7485)	(1.003)	(0.3604)
$\bar{\lambda}_{NSF}$	**1.404*****	0.9869***	1.761***	1.419***
	(0.1226)	(0.1520)	(0.2086)	(0.1210)
$\bar{\lambda}_{LEV}$	**12.12*****	6.780**		11.59**
	(4.339)	(2.781)		(4.342)
φ	**0.1487****	-0.1549		0.1527***
	(0.0594)	(0.1231)		(0.0549)
Fixed-effects				
Bank-Year	Yes	Yes	Yes	Yes
Varying Slopes				
Risk $\times$Bank				Yes
Fit statistics				
Observations	61,485	34,529	26,956	61,485
R^2	0.31270	0.23272	0.32153	0.32605
Within R^2	0.28041	0.07963	0.25404	0.27384

Clustered (yq & Code.CIB) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 10: Demand estimates

This table presents the results for the supply-side estimation. The first column describes the main specification, with a homogenous CRRA coefficient γ. The second (third) columns show the outcome of the estimation when ran only on the asset (liability) side of the balance sheet. The fourth column represents a specification where we allowed for a heterogenous γ_i.

6.3 Cost of regulation

Sanity check: The two arms of the Interbank market. Our model posits that borrowing in the interbank market involves a trade-off between leverage and liquidity. Specifically, if our model is accurate, the relative tightness of the leverage constraint compared to the liquidity coverage ratio–as measured by the ratio $\frac{e^{(1-LEV_{it})}}{e^{(1-LCR_{it})}}$– should be higher for lenders than for borrowers. In other words, borrowers should exhibit a greater need for liquidity relative to their leverage constraints compared to lenders. Empirically, we observe precisely this pattern, as illustrated in figure 6. Over the 12 years period, the number of borrowers consistently declined while the number of lenders increased, yet the leverage-liquidity gap between these two groups remained stable.

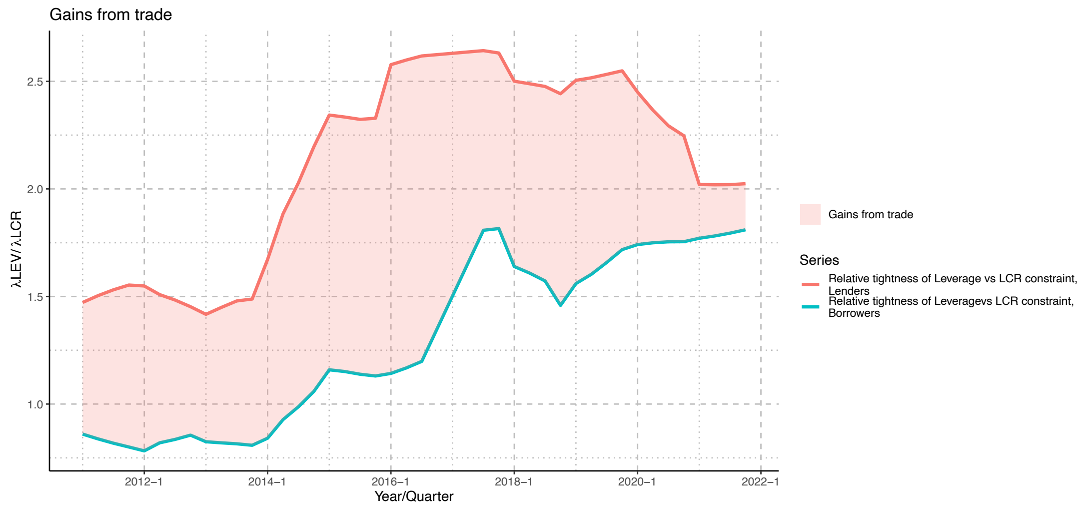


Figure 6: Leverage-Liquidity gap

The figure depicts the weighted average leverage-liquidity gap between lenders of reserves and borrowers of reserves. Lenders were consistently more liquid relative to their leverage than borrowers.

The cost of regulation: Our structural parameter estimates naturally lend themselves into a quantification exercise. We can compute the marginal cost of regulation for a given item j held by bank i as follows:

$$\text{RegCost} = \sum_k \bar{\lambda}_k e^{(1-\text{Ratio}_{ikt})}(1 - X_{ijt}\frac{\partial \text{Ratio}_{ikt}}{\partial X_{ijt}})\omega_{jk}$$

Figure 7 depicts the evolution of the regulatory cost of loan provision. Over the sample period, this cost remained relatively stable. As we will show in the next few sections, this is despite a sharp increase of the regulatory costs induced by reserves.

Figure 8 depicts the marginal cost (benefit) of taking deposits. As a source of stable

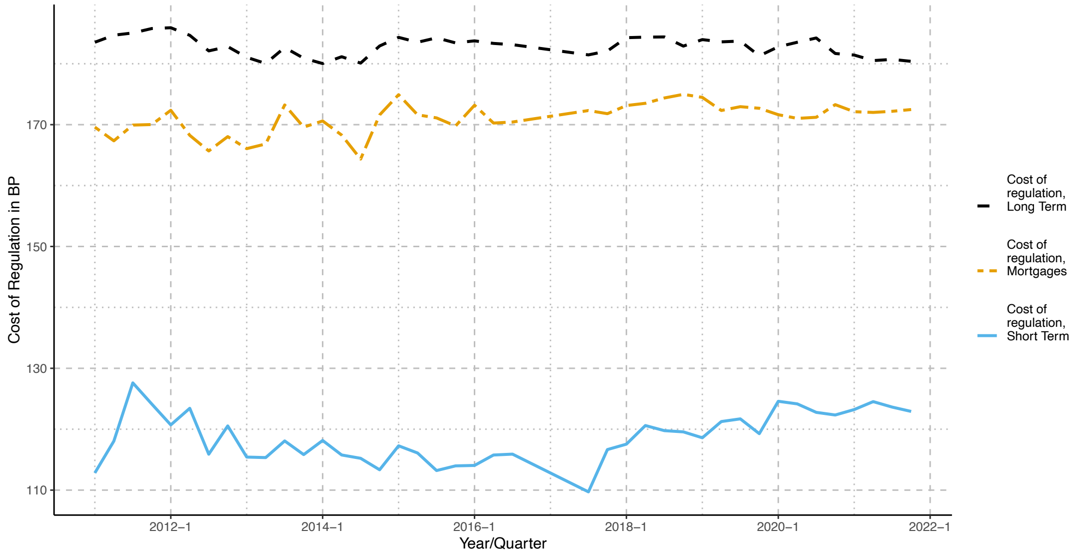


Figure 7: Regulatory cost of lending provision

The figure depicts the weighted average marginal regulatory cost of providing different types of loans.

funding subject to few runs, insured household deposits and time deposits are highly beneficial to hold. As banks became more liquid at the beginning of the period, the benefit of holding deposits increased sharply, allowing them to mitigate risks associated with short-term liquidity pressures. However, as the funding positions of banks deteriorated, it became gradually less interesting to hold liquid demand deposits, which encourages banks to tilt towards time deposits. This back and forth is clear when looking at the regulatory cost of overnight non financial corporation deposits, that temporarily dips into the negative as the liquidity of banks increase to then reverse course once the funding structure deteriorates too much.

Decomposing the cost of regulation: To quantify the regulatory costs specifically induced by the reserves injected during quantitative easing (QE), we recompute the marginal regulatory cost for each regulatory constraint k, excluding reserves and their corresponding liabilities from the ratios:

$$\text{RegCost}_k = \bar{\lambda}_k e^{(1-\text{Ratio}_{ikt})}(1 - X_{ijt}\frac{\partial \text{Ratio}_{ikt}}{\partial X_{ijt}})\omega_{jk}$$

The difference between the regulatory cost calculated without reserves and that including reserves represents the total contribution of excess reserves to the marginal regulatory cost.

Since banks can issue certificates of deposit or commercial paper to transform wholesale deposits into longer-term funding, we cannot assume that a decrease in cen-

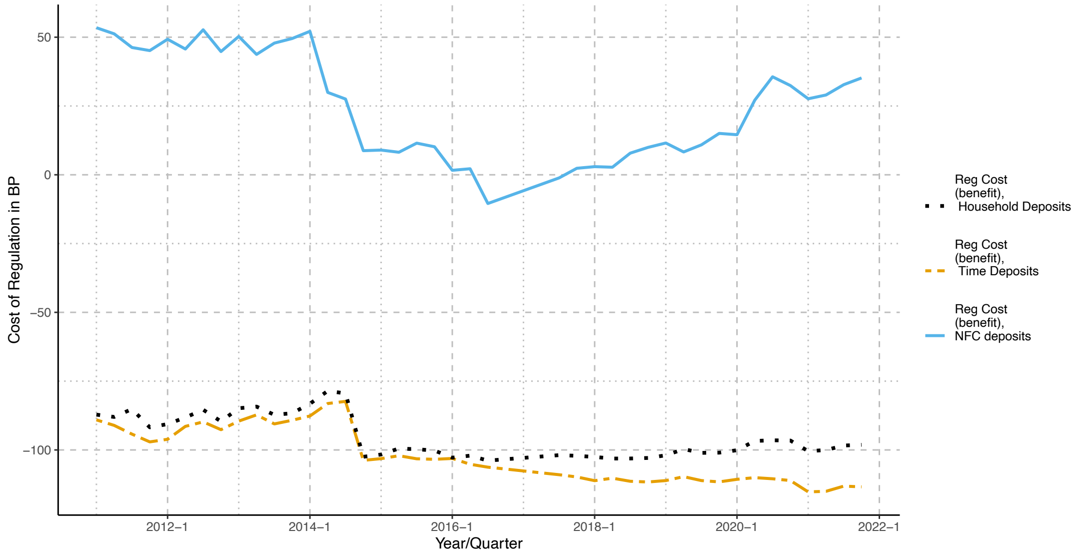


Figure 8: Regulatory cost of lending provision

The figure depicts the weighted average marginal regulatory cost of taking in different types of deposits.

tral bank reserves will lead to a one-to-one reduction in wholesale deposits. Therefore, we adopt a conservative assumption: a decrease in central bank reserves reduces the total quantity of wholesale funding while maintaining its relative composition intact.

Figure 9 depicts the marginal cost of excess reserves for the average long-term lender. We define long-term loans as any loans with an initial maturity of more than one year. This cost steadily increases over time and represents as much as 13% of the total return on a new mortgage in Q4 2021. Intuitively, the average lender should not be representative of the cost of lending: banks self-select into lending, and those lending less are likely facing higher costs.

To understand how the costs induced by reserves are spread over the sample, we depict the marginal cost of reserves for banks in the lower quintile and the higher quantile of the size distribution, respectively in figure 10 and 11. The contrast is striking: the cost of reserves is much greater for large banks, owing to their funding structure. As their NSF ratio is already high, their net stable funding cost skyrockets when they have to absorb large amounts of wholesale deposits. As such, these banks should be more inclined towards shorter term investments and disengage form long-term lending.

Smaller banks, on the other hand, suffer from the sheer volume of reserves and the effect it has on their balance sheets. A large part of the cost they have to bear is driven by the leverage ratio, since their funding structure is mostly composed of stable deposits. Both of these estimates suggest that fully excluding central bank reserves from the leverage ratio calculation could have reduced the marginal cost of lending by up to 5 basis points. This would alleviate the regulatory burden on both large and small banks, potentially encouraging more lending activity across the banking sector.

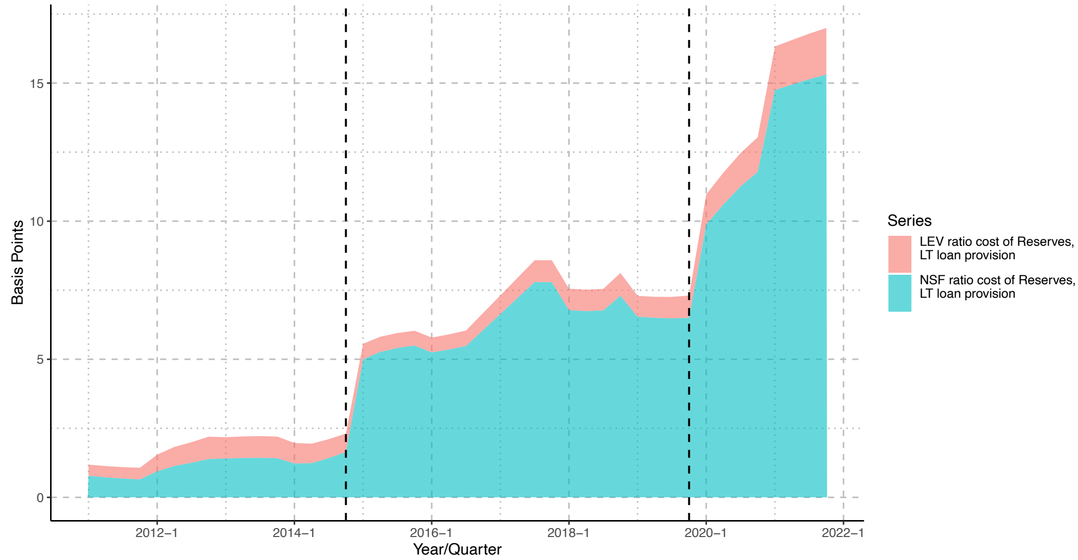


Figure 9: Regulatory cost of reserves for the average lender

The figure depicts the lending volume-weighted average of the marginal contribution of reserves to the regulatory cost of long term loans, in basis points. The vertical dashed lines denote the start of the two large episodes of quantitative easing.

7 Counterfactuals

The abridged recipe to compute our counterfactuals is provided in appendix D. We compute our preliminary counterfactuals on the Banque de France dataset and impose clearing of the interbank market at the country level.

7.1 LSAP

We compute the counterfactual lending output for alternate quantities of reserves, starting from our latest data point, 2021 Q4. At this point in time, reserves were at their maximum. As such, we compute counterfactual equilibria for a 20% (800 billions) decrease in central bank reserves, a 50% (2 trillions) decrease, and a 80% (3.2 trillions) decrease. We assume that the reversal in LSAP will have a directly proportional effect on the endowment of banks. We find that reserves are initially expanding the volume of credit, but this positive impact plateaus and then reverses. We find that a 5% decrease in lending volume relative to the maximum, that would have been attained at 2 trillions euros of asset purchases. Nonetheless, quantitative easing is overall a net

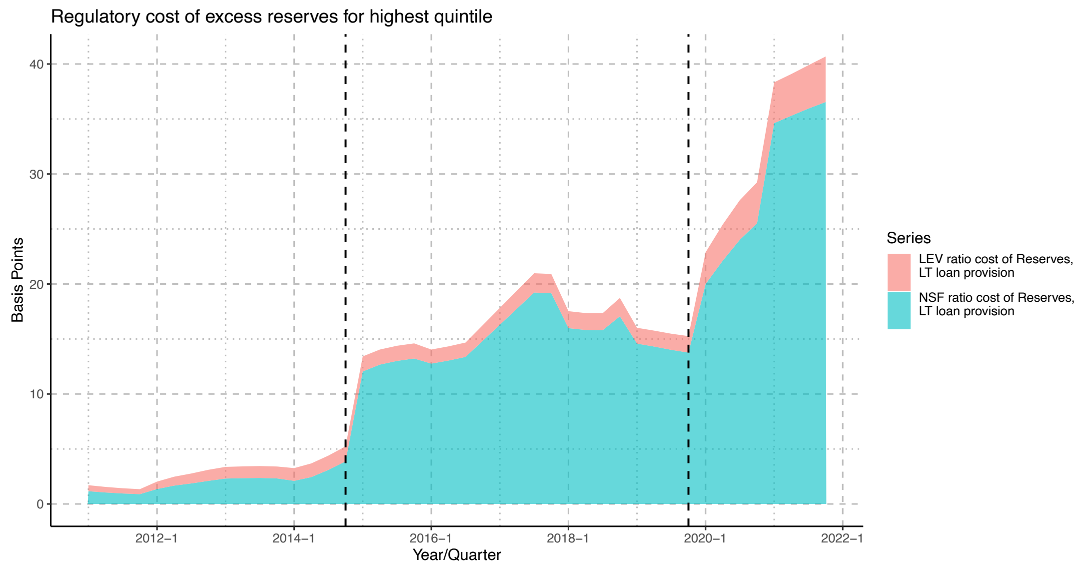


Figure 10: Regulatory cost of reserves for large banks

The figure depicts the assets-weighted average for banks in the highest quintile, of the marginal contribution of reserves to the regulatory cost of long term loans, in basis points. The vertical dashed lines denote the start of the two large episodes of quantitative easing.

positive for lending outcomes, with an aggregate lending volume that is around 3% higher than what would have been without the policy.

Figure 12 depicts this quasi-Laffer curve of excess reserves. Note that the main force in our model that drives the increase in the quantity of wholesale funding, and therefore the deterioration in lending provision, is the limited size of the deposit market, as well as the market power of deposit taking banks.

8 Conclusion

We provide a novel quantification of the cost of regulation through a structural model. While regulation serves a legitimate purpose and likely enhances value by reducing the likelihood of future crises, it inherently transforms banks' balance sheets. This transformation is intentional, aiming to create stronger and more resilient banks by altering their asset and liability compositions. However, such regulatory changes may conflict with other policies affecting bank balance sheets, potentially leading to imbalances and reduced lending output. Our calculations show that the interaction between large-scale asset purchases and Basel III regulations increased the cost of lending by up to 14% of the total return on a new mortgage in 2021 Q4. This additional cost led to a 5% reduction in aggregate lending provision compared to an optimal policy aimed at maximizing bank lending expansion. Such a contractionary outcome matters, as it is directly at odds with the expansionary nature of quantitative easing.

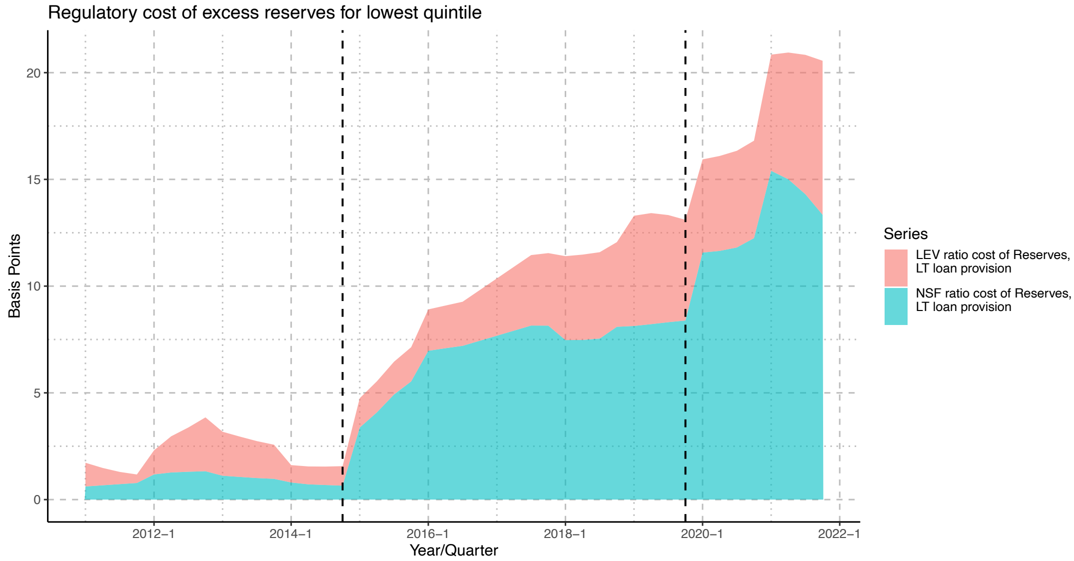


Figure 11: Regulatory cost of reserves for small banks

The figure depicts the assets-weighted average for banks in the smallest quintile, of the marginal contribution of reserves to the regulatory cost of long term loans, in basis points. The vertical dashed lines denote the start of the two large episodes of quantitative easing.

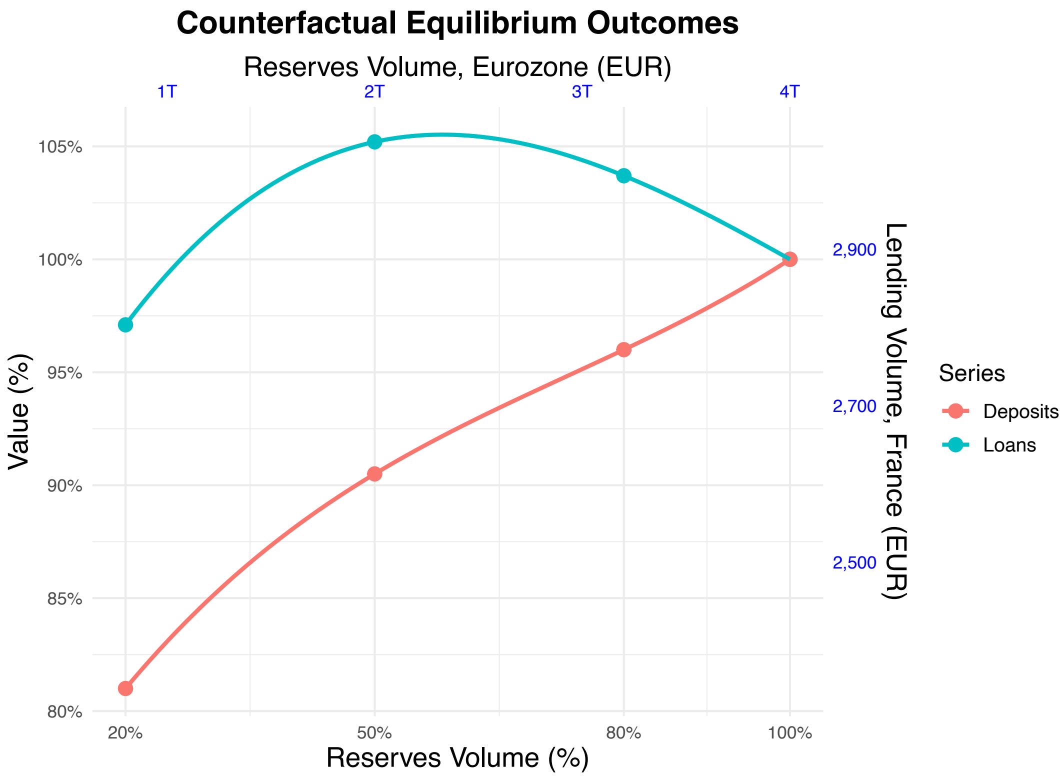


Figure 12: Counterfactual LSAP volumes

The figure depicts counterfactual aggregate lending volume and aggregate deposit volumes if we cancel quantitative easing.

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A A simple theoretical model

In the following, we solve a simplified version of the model, where there are two banks, $\{i, j\}$, and the deposit/lending markets are greatly simplified.

At its core, the model is a revisited Monti-Klein banking model, where Banks compete à la Bertrand for loans and deposits and exert power at both ends of the financial intermediation market. We differentiate reserves from the rest of the money market, that we denote as securities, as this allows us to properly study the impact of the injection of vast quantities of reserves since the Global Financial Crisis. Banks maximize the returns from a mean-variance portfolio of loans and securities, while subject to a funding constraint (the balance sheet must clear) and a regulatory liquidity constraint.

WLOG, let us refer to the bank in question as i and its competitor as j. i can hold securities S_i, loans L_i, can take deposits D_i, and is allocated equity E_i and reserves $Q_{i,R}$ at the beginning of the period. i can trade reserves on the interbank market in the form of loans, and we denote the amount lent/borrowed as $\Delta Q_{i,R}$. Accordingly, the balance sheet of the bank borrowing on the interbank market is slightly different from the balance sheet of the lending bank.

Borrowing Bank

Assets	Liabilities
S_i	D_i
L_i	E_i
$Q_{i,R} + \Delta Q_{i,R}$	$\Delta Q_{i,R}$ (IOU)

Lending Bank

Assets	Liabilities
S_i	D_i
L_i	E_i
$Q_{i,R} + \Delta Q_{i,R}$	
$-\Delta Q_{i,R}$ (IOU)	

Bank i set interest rates $R_{i,L}$ and $R_{i,D}$, which will determine the equilibrium quantities D_i and L_i in tandem with the interest rates set by bank j, according to the following equations

$$L_i = \bar{D}\frac{e^{\alpha_D R_{i,D}}}{1 + e^{\alpha_D R_{i,D}} + e^{\alpha_D R_{j,D}}}$$
$$L_i = \bar{L}\frac{e^{\alpha_D R_{i,L}}}{1 + e^{\alpha_L R_{i,L}} + e^{\alpha_L R_{j,L}}}$$

Where $\bar{D}$ and $\bar{L}$ represent the sizes of their respective markets. To simplify the system, let us take $\bar{L} = \bar{D} = 1$

Further, securities pay an exogenous interest rate, R_S. To keep things simple, we consider that it is an exogenous spread above the risk free rate, R_F, which is the interest rate paid on reserves.

Let us consider the case where the risk borne by the loan portfolio is independent from the securities risk. That is,

$$[S_i, L_i]\Sigma[S_i, L_i]' = \sigma_L^2 L_i^2 + \sigma_S^2 S_i^2$$

Further, when risks are independent and assuming that both banks share the same risk aversion, we can ignore the γ coefficient as it can be included in σ^2 WLOG.
Since central bank reserves' main advantage over other assets are their liquidity, we first consider the case where the bank is only subject to the LCR constraint. In such case, the benefit of supplementary reserves is clear: by slackening the liquidity constraint, it allows the banks to expand their balance-sheet by taking in more deposits.
Following existing literature , we assume that the weighting of the LCR items has the following magnitude:

$$w_{L,LCR} < \beta_{D,LCR} < w_{S,LCR} < w_{R,LCR} = 1$$

That is, loans fail to provide sufficient liquidity to cover for deposits, but securities and reserves are liquid enough to cover for outflows of deposits. Banks need to hold some amount of liquid assets and cannot restrict their activity to lending.
As such, the bank's problem is the following:

$$\max_{D_i, L_i, S_i, \Delta Q_{i,R}} S_i R_S + L_i R_{i,L}(L_i) - L_i R_{i,D} + \Delta Q_{i,R}(R_F - R_{ITB}) - \frac{\sigma_L^2}{2} L_i^2 - \frac{\sigma_s^2}{2} S_i^2$$

$$S_i + L_i + Q_{i,R} = E_i + D_i \qquad (BS)$$

$$\beta_{D,LCR} D_i \leq w_{R,LCR}(Q_{i,R} + \Delta Q_{i,R}) + w_{L,LCR} L_i + w_{S,LCR} S_i \qquad (LCR)$$

$$L_i \geq 0 \qquad (NNC)$$

Where $\Delta Q_{i,R}$ denotes the amount of reserves **borrowed** on the interbank market. Therefore, if $\Delta Q_{i,R} < 0$, the bank is lending reserves. Please note that maximising over interest rates or quantities result in the same FOCs, but we chose to maximise over quantities in this section as it eases the understanding of the comparative statics for the aggregate quantities in this system.

A.1 First Order Conditions

Note that as constraints are affine the duality gap is equal to 0 and we can therefore solve the problem through Karush-Kuhn-Tucker conditions. Assuming the LCR constraint is binding[33] and that the solution is an interior solution, the FOCs that describe

[33]It can be shown through the dual problem that the LCR constraint is always binding if $R_{ITB} > R_F$.

an equilibrium of the game are:

$$-R_{i,D}(D_i^*) - D_i^* R'_{i,D}(D_i^*) - \beta_{D,LCR}\lambda_{LCR} + \lambda_{BS} = 0 \tag{A.1}$$

$$R_S - \sigma_S^2 S_i^* + w_{S,LCR}\lambda_{LCR} - \lambda_{BS} = 0 \tag{A.2}$$

$$R_{i,L}(L_i^*) + L_i^* R'_{i,L}(L_i^*) - \sigma_L^2 L_i^* + w_{L,LCR}\lambda_{LCR} - \lambda_{BS} = 0 \tag{A.3}$$

$$R_F - R_{ITB} + \lambda_{LCR} = 0$$

$$\Leftrightarrow \lambda_{LCR} = R_{ITB} - R_F \tag{A.4}$$

$$\beta_{D,LCR} D_i^* - Q_{i,R} - w_{L,LCR} L_i^* - w_{S,LCR} S_i^* = \Delta Q_{i,R} \tag{A.5}$$

$$S_i^* + L_i^* + Q_{i,R} = E_i + D_i^* \tag{A.6}$$

Note that $w_{R,LCR} = 1$. This is a system of 6 equations and 6 unkwowns (That is, D_i, L_i, ΔQ_i, λ_{BS} and λ_{LCR}), that is ultimately dependent on $R_{ITB} - R_F$, and the functions $R_{i,L}(L_i)$, $R_{i,D}(D_i)$. In order to pin the equilibrium, we need to tie the balance sheets of bank i and bank j together through the deposit market, the lending market, and the reserves market.

Given that $\lambda_{LCR} = R_{ITB} - R_F$, we can characterize the Cournot-Nash quantities D_i^* and L_i^* and the optimal investment in securities S_i^* as functions of λ_{BS}:

$$L_i^*(\lambda_{BS}) = \frac{\lambda_{BS} - R_{i,D}(D_i^*) - \beta_{D,LCR}(R_{ITB} - R_F)}{R'_{i,D}(D_i^*)} \tag{A.7}$$

$$S_i^*(\lambda_{BS}) = \frac{R_S + w_{S,LCR}(R_{ITB} - R_F) - \lambda_{BS}}{\sigma_S^2} \tag{A.8}$$

$$L_i^*(\lambda_{BS}) = \frac{R_{i,L}(L_i^*) + w_{L,LCR}(R_{ITB} - R_F) - \lambda_{BS}}{\sigma_L^2 - R'_{i,L}(L_i^*)} \tag{A.9}$$

Note that as these quantities depend on the inverse demand function faced by the bank and the equilibrium on the markets, their comparative statics are not entirely straightforward as is. We can also characterize λ_{BS} and $\Delta Q_{i,R}$ from *A.6*, A.5 and the three equations characterizing D_i^*, L_i^* and S_i^*:

$$\lambda_{BS}^* = \frac{\frac{R_{i,L}(L_i^*)+w_{L,LCR}(R_{ITB}-R_F)}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{R_S + w_{S,LCR}(R_{ITB}-R_F)}{\sigma_S^2} + \frac{R_{i,D}(D_i^*)+\beta_{D,LCR}(R_{ITB}-R_F)}{R'_{i,D}(D_i^*)} + Q_{i,R} - E_i}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} \tag{A.10}$$

$$\Delta Q_{i,R} = \beta_{D,LCR} D_i^* - Q_{i,R} - w_{L,LCR} L_i^* - w_{S,LCR} S_i^* \tag{A.11}$$

From there, it is relatively straightforward to compute the change in balance-sheet items following an increase in reserves (holding the interbank rate R_{ITB} fixed).

$$\frac{\partial L_i^*}{\partial Q_{i,R}} = \frac{\frac{1}{R'_{i,D}(D_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} \tag{A.12}$$

$$\frac{\partial L_i^*}{\partial Q_{i,R}} = \frac{-\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} \tag{A.13}$$

$$\frac{\partial S_i^*}{\partial Q_{i,R}} = \frac{-\frac{1}{\sigma_S^2}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} \tag{A.14}$$

Which implies that the borrowed (lent) amount of reserves on the interbank market is strictly decreasing (increasing) in the quantity of reserves on bank i's balance sheet.

$$w_{L,LCR} - 1 < \frac{\partial \Delta Q_{i,R}^*}{\partial Q_{i,R}} < w_{S,LCR} - 1 < 0 \tag{A.15}$$

Note that we can also show that S_i^* is an increasing function of the spread $R_{ITB} - R_F$ and the quantities D_i^* and L_i^* are decreasing function of the interbank spread through tedious yet straightforward calculus that we omit here in the interest of space.

A.2 Deposit and Loan market

WLOG, we will describe the deposit market below. The deposit market and the lending market follow the same algebra, with the difference that $\alpha_D > 0$ and $\alpha_L < 0$, that is the demand for deposits increases in the rate paid on deposits and the demand for loans decreases in the rate charged on loans.
We have

$$L_i = \frac{e^{\alpha_D R_{i,D}}}{1 + e^{\alpha_D R_{i,D}} + e^{\alpha_D R_{j,D}}}$$
$$1 - D_i - D_j = \frac{1}{1 + e^{\alpha_D R_{i,D}} + e^{\alpha_D R_{j,D}}}$$

Which yields the inverse demand curve faced by bank i

$$R_{i,D} = \frac{1}{\alpha_D} \ln\left(\frac{D_i}{1 - D_i - D_j}\right) \tag{A.16}$$

Or, rewritten as a function of the interest rate $R_{j,D}$

$$R_{i,D} = \frac{1}{\alpha_D} \ln\left(\frac{D_i}{1-D_i}(1+e^{\alpha_D R_{j,D}})\right) \tag{A.17}$$

Crucially, this functional form ensures that $R'_{i,D} > 0$ and that $R'_{i,L} < 0$.

A.3 Interbank (reserves) market

For the interbank market to clear, we must have that

$$\Delta Q_{i,R} = -\Delta Q_{j,R}$$

When substituting A.5 into this equation on both sides, we get

$$Q_{i,R} - Q_{j,R} = (D_i - D_j)\beta_{D,LCR} + (S_j - S_i)w_{S,LCR} + (Lj - Li)w_{L,LCR} \tag{A.18}$$

Lemma 1. *$\Delta Q_{i,R}$ is a decreasing function of the interbank spread $R_{ITB} - R_F$.*

Proof. To see that $\Delta Q_{i,R}$ is a decreasing function of $R_{ITB} - R_F$, take A.5 and replace the values for L_i, S_i, D_i using A.1, A.3 and the budget constraint. We can then express $\Delta Q_{i,R}$ as a function of parameters, including the spread $R_{ITB} - R_F$. Then, solving for the derivative of this object w.r.t. $R_{ITB} - R_F$ using the chain rule yields a negative function.

$$\begin{aligned}
\Delta Q_{i,R} &= \beta_{D,LCR} D_i^* - w_{L,LCR} L_i^* - w_{S,LCR} S_i^* - Q_{i,R} \\
&= (w_{S,LCR} - w_{L,LCR})L_i^* - (w_{S,LCR} - \beta_{D,LCR})D_i^* - (1 - w_{S,LCR})Q_{i,R} - w_{S,LCR}E_i \\
&[...] \\
\frac{\partial \Delta Q_{i,R}}{\partial R_{ITB} - R_F} &\propto -\sigma_S^2(\beta_{D,LCR} - w_{L,LCR})^2 - R'_{i,D}(D_i^*)(w_{S,LCR} - w_{L,LCR})^2 - (\sigma_L^2 - R'_{i,L}(L_i^*))(w_{S,LCR} - \beta_{D,LCR})^2 \\
\frac{\partial \Delta Q_{i,R}}{\partial R_{ITB} - R_F} &< 0
\end{aligned}$$

Q.E.D. □

Since $\Delta Q_{i,R}$ is a decreasing function of $R_{ITB} - R_F$, and since the sign of $\Delta Q_{i,R}$ and $\Delta Q_{j,R}$ are opposite, it is clear that when $R_{ITB} - R_F$ moves, the two quantities $|\Delta Q_{i,R}|$ and $|\Delta Q_{j,R}|$ move in opposite directions. Therefore, the interest rate $R_{ITB} - R_F$ moves to ensure market-clearing, tying the two balance sheet together through the interbank market. This is very intuitive: as the interbank spread increases, a borrowing bank would want to borrow more but a lending bank would want to lend more.

A.4 Comparative statics

We now have all of the ingredients needed to give an intuition for the effect of the following monetary easing policies:

1. Large Scale Asset Purchases when banks are the final counterparty to the purchases
2. Large Scale Asset Purchases when non-banks are the final counterparty to the purchases
3. TLTRO

A.4.1 LSAP with bank i as the final counterparty

A LSAP transaction with bank i as a final counterparty to the transaction is akin to injecting a quantity of reserves $\Delta Q_{i,R}$ into the balance sheet of bank i.

This leads to an increase in D_i^*, a decrease in L_i^*. This is reciprocated on bank j balance sheet by a decrease in D_j^* as it loses market share and an increase in L_j^* as it gains market share. Both banks decrease their security holdings S and the interbank rate R_{ITB} adjusts downwards as a result of the improvement in the liquidity situation.

Proposition 1. *Injecting $\Delta Q_{i,R}$ reserves into Bank i's balance sheet results in*

- *An* ***increase*** *in deposits of size ΔL_i with* $0 < \frac{\frac{\Delta Q_{i,R}}{R'_{i,D}(D_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} < \Delta L_i$
- *A* ***decrease*** *in lending of size ΔL_i with ΔL_i with* $0 < -\Delta L_i < \frac{\frac{\Delta Q_{i,R}}{\sigma_L^2 - R'_{i,L}(L_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}}$
- *A* ***decrease*** *in securities holdings of size ΔS_i with* $0 < \frac{\frac{\Delta Q_{i,R}}{\sigma_Q^2}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} < -\Delta S_i$
- *A* ***decrease*** *in the interbank spread $R_{ITB} - R_F$.*

Conversely, bank j balance sheet changes in the following way:

- *Deposits* ***decrease*** *by a less than proportional amount, $-\Delta L_j < \Delta L_i$*
- *Lending* ***increases*** *by a less than proportional amount $\Delta L_j < -\Delta L_i$*
- *Securities holdings* ***decrease*** *by a less than proportional amount $-\Delta S_j < -\Delta S_i$*

As a result, ***the expansion in reserves leads to a growth in deposits and crowds out lending and securities*** *from the balance sheet of the banking system.*

Proof. Let us show WLOG the proof for Deposits D_i and D_j. With trivial substitutions, the proof applies for lending and securities holdings.

Given the derivative of D_i^* w.r.t. the reserve endowment $Q_{i,R}$, holding the interbank rate fixed an increase of endowment of size $\Delta Q_{i,R}$ leads to an increase in deposits of size

$$\frac{\frac{\Delta Q_{i,R}}{R'_{i,D}(D_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}}$$

This, in turn, leads to an imbalance on the interbank market. Indeed, from A.15, $\frac{\partial \Delta Q_{i,R}}{\partial Q_{i,R}} < 0$ And assuming that the interbank market cleared before the reserve injection, we must now have that

$$\Delta Q_{i,R} < -\Delta Q_{j,R}$$

Suppose that $\Delta Q_{i,R}$ was negative (bank i lent on the interbank market). After the reserve injection, $\Delta Q_{i,R} < -\Delta Q_{j,R}$, which means that bank i lends more than what bank j requires. There is excess lending on the interbank market and the interbank spread needs to adjust for the market to clear. A decrease in the interbank spread $R_{ITB} - R_F$ leads to an increase in the quantity borrowed by bank j, (hence a decrease in $-\Delta Q_{j,R}$) and to a decrease in the quantity lent by bank i (hence an increase in $\Delta Q_{i,R}$). Since $\Delta Q_{i,R}^*$ is a continuous function of $R_{ITB} - R_F$, the intermediate value theorem yields that there must be a new equilibrium in the interbank market[34] for some rate $R'_{ITB} < R_{ITB}$. If $\Delta Q_{i,R}$ was positive (bank i borrows on the interbank market), the same argument runs its course: After the reserve injection bank i borrows less than bank j offers, which leads to the same imbalance (there is excess lending on the interbank market). Therefore the spread must adjust downwards.

As D_i^* is a negative function of the spread, a decrease in the spread must lead to a further increase in D_i^*. As such,

$$\frac{\frac{\Delta Q_{i,R}}{R'_{i,D}(D_i^*)}}{\frac{1}{\sigma_L^2 - R'_{i,L}(L_i^*)} + \frac{1}{\sigma_S^2} + \frac{1}{R'_{i,D}(D_i^*)}} < \Delta L_i$$

Let us now show that $-\Delta L_j < \Delta L_i$. First, note that A.17 rewrites

$$D_j^* = \frac{e^{\alpha_D R_{j,D}}}{1 + e^{\alpha_D R_{j,D}}}(1 - D_i^*)$$

Which clearly yields $-1 < \frac{\partial L_j^*}{\partial L_i^*} < 0$. Therefore, an increase in D_i^* results in a less than proportional decrease in D_j^* before accounting for the effects of the change in the interbank rate. It turns out that the change in the interbank rate only reinforces

[34]Which implies optimality for balance-sheet quantities on either side.

this further, as the interbank spread decreased and D_j^* is a decreasing function of the interbank spread.

Q.E.D. $\square$

A.4.2 LSAP with non-bank as the final counterparty

Such a transaction is equivalent to injecting $\Delta Q_{i,R}$ into bank i balance sheet as well as increasing the size of the deposit market by $\Delta Q_{i,R}$, such that $\bar{D} = 1 + \Delta Q_{i,R}$.

This results in an increase in lending and deposit take-up in equilibrium, as bank j increases its lending

Injection of reserves alone ($+Q_{i,R}$, akin to QE with Bank as a counterparty): total deposits increase, total lending decrease, total security holdings decrease. D_i increases, D_j decreases, L_i decreases, L_j increases, both S_i and S_j decrease.
Injection of reserves and deposits ($+Q_{i,R}$, $+\bar{D}$, akin to QE with Non-Bank as a counterparty): total deposits increase, effect on lending unclear, total security holdings decrease. D_i increases, D_j unclear, L_i unclear, L_j increases, S_i decreases and S_j unclear.
Injection of reserves and equity ($+Q_{i,R}$, $+E_i$, akin to TLTRO): total deposits decrease, total lending increases, total security holdings increase. D_i decreases, D_j increases, L_i increases, L_j decreases, S_i increases and S_j increases.

Fundamentally, the big tension in this model is between balance sheet space (the cost of which is captured by λ_{BS}) and necessary liquidity coverage (the cost of which is captured by $\lambda_{LCR} = R_{ITB} - R_f$).Profit opportunities are limited by increasingly costly funding from deposits, and scarce lending opportunities. As such, injecting reserves takes up balance sheet space, which leads to a crowding out of lending and deposit-taking activities. The interbank rate clears the market, and is directly decreasing in the quantity of reserves in the system. When injecting reserves in a way that also increases the size of the balance sheets (TLTRO or QE with nonbanks), the negative effect on lending is alleviated, but there might be some crowding out of other balance sheet elements: TLTRO crowds out deposits, which means that when the policy end, banks might face funding issues. A dynamic model with sticky deposits and lending might be informative on the effect of QT/reversing the policies.

B Computation of the derivative of the regulatory shadow costs

We drop the time subscripts to reduce notational clutter. Note that the regulatory ratios are defined as

$$ratio_{i,LEV} = \frac{1}{\delta_{i,LEV}} \frac{E_i}{\sum_j w_{LEV,j} A_{ij} + \hat{Q}_i + \mathbb{1}_{\Delta Q_{i,R}>0} \Delta Q_{i,R}} \tag{B.19}$$

$$ratio_{i,CET1} = \frac{1}{\delta_{i,CET1}} \frac{E_i}{\sum_j w_{CET1,j} A_{ij}} \tag{B.20}$$

$$ratio_{i,NSF} = \frac{\sum_j \beta_{j,NSF} L_{ij} + \beta_{E,NSF} E_i}{\sum_j w_{j,NSF} A_{ij}} \tag{B.21}$$

$$ratio_{i,LCR} = \frac{\sum_j w_{j,LCR} A_{ij} + Q_{i,R} + w_{R2,LCR} \Delta Q_{i,R}}{\sum_j \beta_{j,LCR} L_{ij,LCR} + \beta_{E,LCR} E_i} \tag{B.22}$$

where we set the $\delta_{LEV} = 0.03$[35] and $\delta_{CET1} = 0.06$ and risk weights are specified in Appendix **??**.

Agents fully internalize the endogenous impact that their balance sheet activity may have on the shadow cost of regulation. This means

$$\frac{\partial \lambda_{ik}}{\partial X_{ij}} = \frac{\partial \lambda_{ik}}{\partial ratio_{ik}} \frac{\partial ratio_{ik}}{\partial X_{ij}} \tag{B.23}$$

Obtaining the first term is easy. For example, when $\lambda_{ikt} = \bar{\lambda}_k e^{(1-ratio_{ik})}$, then

$$\frac{\partial \lambda_{ik}}{\partial ratio_{ik}} = -\lambda_k e^{(1-ratio_{ik})}$$

where $ratio_{ik}$ corresponds to the regulatory ratio k in question and the derivative is evaluated at the corresponding value of that ratio for bank i (at time t).

However, the second term in Eq. (B.23) depends on the identity of the balance sheet item X_j and which regulatory ratio k we refer to. For assets side items A_{ij}

$$\frac{\partial ratio_{i,LEV}}{\partial A_{ij}} = -ratio_{i,LEV} \frac{w_{j,LEV}}{\sum_j w_{j,LEV} A_{ij} + \hat{Q}_i + \mathbb{1}_{\Delta Q_{i,R}>0} \Delta Q_{i,R}}$$

$$\frac{\partial ratio_{i,CET1}}{\partial A_{ij}} = -ratio_{i,CET1} \frac{w_{j,CET1}}{\sum_j w_{j,CET1} A_{ij}}$$

$$\frac{\partial ratio_{i,NSF}}{\partial A_{ij}} = -ratio_{i,NSF} \frac{w_{j,NSF}}{\sum_j w_{j,NSF} A_{ij}}$$

$$\frac{\partial ratio_{i,LCR}}{\partial A_{ij}} = \frac{w_{j,LCR}}{\sum_j \beta_{j,LCR} L_{ij} + \beta_{E,LCR} E_i}$$

[35] This is a binding minimum requirment for all the banks. However, it may be higher for G-SIIs.https://www.bankingsupervision.europa.eu/banking/srep/html/lrp2g.en.html

For liability items L_{ij}

$$\frac{\partial ratio_{i,LEV}}{\partial L_{ij}} = 0$$
$$\frac{\partial ratio_{i,CET1}}{\partial L_{ij}} = 0$$
$$\frac{\partial ratio_{i,NSF}}{\partial L_{ij}} = \frac{\beta_{j,NSF}}{\sum_j w_{j,NSF} A_{ij}}$$
$$\frac{\partial ratio_{i,LCR}}{\partial L_{ij}} = -ratio_{i,LCR} \frac{\beta_{j,LCR}}{\sum_j \beta_{j,LCR} L_{ij,LCR} + \beta_{E,LCR} E_i}$$

For traded reserves ΔQ_i

$$\frac{\partial ratio_{i,LEV}}{\partial \Delta Q_i} = -ratio_{i,LEV} \frac{\mathbb{1}_{\Delta Q_{i,R}>0}}{\sum_j w_{j,LEV} A_{ij} + \hat{Q}_i + \mathbb{1}_{\Delta Q_{i,R}>0} \Delta Q_{i,R}}$$
$$\frac{\partial ratio_{i,CET1}}{\partial \Delta Q_i} = 0$$
$$\frac{\partial ratio_{i,NSF}}{\partial \Delta Q_i} = 0$$
$$\frac{\partial ratio_{i,LCR}}{\partial \Delta Q_i} = \frac{1}{\sum_j \beta_{j,LCR} L_{ij} + \beta_{E,LCR} E_i}$$

Let us then analyze the case with estimated slopes for scaled λ. That is when $\lambda_{ikt} = \bar{\lambda}_k e^{\xi_k (1-ratio_{ik})}$, then

$$\frac{\partial \lambda_{ik}}{\partial ratio_{ik}} = -\xi_k \lambda_k e^{\xi_k (1-ratio_{ik})}$$

The second part of the product in Equation (B.23) is as before.

C Granular Instrumental Variables for Logit Demand Markets

In the corporate lending market, we can re write the market share as

$$\log(L_{i,nt}) = \alpha LrL_{i,nt} + \beta X_{L,i,nt} + \xi_{L,i,nt} + \log(L_{0,nt}),$$

where $L_{0,nt}$ is proportional to the sum of the exponentials of the utilities of all banks:

$$L_{0,nt} \propto \sum_k \exp(\alpha LrL_{k,nt} + \beta X_{L,k,nt} + \xi_{L,k,nt}).$$

This formulation implies that for any bank $k \neq i$, the idiosyncratic demand shocks $\xi_{L,k,nt}$ serve as valid instruments for the price, as they are exogenous and satisfy

$$\mathbb{E}[\xi_{L,k\neq i,nt}\xi_{L,i,nt}] = 0.$$

To construct an exogenous shock proxy, we use a market-share weighted sum of these shocks:

$$\hat{u}_{i,L,nt} = \sum_{k\neq i} \bar{s}_{k,t-1}\xi_{L,k,nt},$$

where $\bar{s}_{t-1}$ represents either the lagged market shares or the time-average of market shares up to period $t-1$. These aggregated shocks can be directly utilized as instruments in own-market estimations and can also be employed as instruments after reweighting in cross-market estimations.

C.1 Algorithm

To estimate the unobservable $\xi_{i,j,t}$, we adopt a sequential estimation approach. First, we perform simple logit regressions for each demand market using the equation

$$\log(s_{ijt}) - \log(s_{0jt}) = \alpha_j r_{ijt} + \beta X_{ijt} + \xi_{ijt}.$$

From these regressions, we recover the estimated demand shocks $\hat{\xi}_{ijt}$, potentially adjusted for time and bank fixed effects. These estimates, while biased for the individual bank i, remain valid as exogenous instruments for other banks' rates $r_{i,l\neq j,t}$. We then construct the instrument vector $\hat{z}_{ijt}$ from the aggregated shocks $\hat{u}_{i,-j,t}$ and proceed to estimate the market model using the Berry-Levinsohn-Pakes (BLP) framework with these instruments. This method ensures robust identification of demand elasticities by leveraging the exogenous variation from competing banks' demand shocks without relying on the Amiti-Weinstein instruments.

To recover the unobservable $\xi_{i,j,t}$ in logit demand markets, we implement the following sequential estimation steps:

1. **Logit Regressions**: Estimate simple logit regressions for each demand market using the basic logit equation:

$$\log(s_{ijt}) - \log(s_{0jt}) = \alpha_j r_{ijt} + \beta X_{ijt} + \xi_{ijt}.$$

2. **Recover Demand Shocks**: Obtain the estimated demand shocks $\hat{\xi}_{ijt}$, adjusting for any fixed effects as necessary.

3. **Construct Instrument Vector**: Build the instrument vector $\hat{z}_{ijt}$ from the aggregated shocks $\hat{u}_{i,-j,t}$:
$$\hat{u}_{i,L,nt} = \sum_{k \neq i} \bar{s}_{k,t-1} \hat{\xi}_{L,k,nt}.$$

4. **Estimate the Market Model**: Utilize the BLP framework to estimate the market model using the instrument vector $\hat{u}_{j,t}$ and the matrix $\hat{Z}_{-j,t}$ as instruments.

D Recipe for counterfactuals

This section details the computation process of the counterfactuals. We start by outlining the gist of the process, and then describe the details of the algebra for each step.

The process consists in 6 steps, and iterates over step 1-5.

0. Fix the shock – be it a change in the structural parameters, a change in the regulatory constraints, a change in the quantity of reserves, etc.

1. Guess assets $\mathbf{A}$ and liabilities $\mathbf{L}$. From the guess, compute traded reserves equilibrium $\mathbf{\Delta Q_R}$.

2. Compute the marginal cost for each bank-level item using the vector guessed assets and liabilities $\{A, L\}$ and the computed reserves equilibrium $\mathbf{\Delta Q_R}$

3. Compute $\boldsymbol{\lambda}_{BS}$, the vector of estimated $\hat{\lambda}_{BS,i}$, by taking for $j \in \mathcal{J} \setminus \{Loans, Deposits\}$
$$\hat{\lambda}_{BS,i} = \frac{\sum_j MC_{i,j} - MR_{i,j}}{|\mathcal{J} \setminus \{Loans, Deposits\}|_i}$$

4. Find the market rates for each $j \in \{Loans, Deposits\}$, that ensure $MC_{i,j} - MR_{i,j} = \hat{\lambda}_{BS,i}$

5. For $j \in \mathcal{J} \setminus \{Loans, Deposits\}$, compute the quantities solving $\hat{\lambda}_{BS,i} = MC_{i,j} - MR_{i,j}$.
   For $j \in \{Loans, Deposits\}$, compute the demand-side quantities implied by the market rates (from the market equilibrium).

6. Update the initial guess using the quantities $\hat{\mathbf{A}}, \hat{\mathbf{L}}$ computed in step 5 and the Jacobian of the functions defining steps 1-5. This yields an updated guess $\{\mathbf{A}', \mathbf{L}'\}$ Iterate over until convergence (i.e. $\{\mathbf{A}, \mathbf{L}\} = \{\mathbf{A}', \mathbf{L}'\}$).

D.1 Reserves market equilibrium

Recall that we start from a guess $\{\mathbf{A}, \mathbf{L}\}$.
In this section, we compute the traded reserves equilibrium $\mathbf{\Delta Q}$.

For the purpose of Jacobian computation to update the guess, we can write down this step as a function

$$f_1 : \{\mathbf{A}, \mathbf{L}\} \mapsto \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}\}$$

D.2 Marginal cost computation

In this section, we compute the marginal costs from the quantities { A,L , $\Delta Q\}$.

For the purpose of Jacobian computation to update the guess, we can write down this step as a function

$$f_2 : \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}\} \mapsto \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}, \mathbf{MC_A}, \mathbf{MC_L}\}$$

D.3 Balance sheet cost computation

For the purpose of Jacobian computation to update the guess, we can write down this step as a function

$$f_3 : \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}, \mathbf{MC_A}, \mathbf{MC_L}\} \mapsto \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}, \mathbf{MC_A}, \mathbf{MC_L}, \hat{\lambda}_{BS}\}$$

D.4 Rates for deposits and loans

For the purpose of Jacobian computation to update the guess, we can write down this step as a function

$$f_4 : \{\mathbf{A}, \mathbf{L}, \mathbf{\Delta Q}, \mathbf{MC_A}, \mathbf{MC_L}, \hat{\lambda}_{BS}\} \mapsto \{\mathbf{MC_A}, \mathbf{MC_L}, \mathbf{MR_A}, \mathbf{MR_L}, \hat{\lambda}_{BS}\}$$

D.5 Quantities implied by the model

For the purpose of Jacobian computation to update the guess, we can write down this step as a function

$$f_5 : \{\mathbf{MC_A}, \mathbf{MC_L}, \mathbf{MR_A}, \mathbf{MR_L}, \hat{\lambda}_{BS}\} \mapsto \{\mathbf{A}, \mathbf{L}\}$$

D.6 Iteration

By the chain rule, we can define a function $f : \{\mathbf{A}, \mathbf{L}\} \mapsto \{\mathbf{A}', \mathbf{L}'\}$ where

$$f = f_1 \circ f_2 \circ f_3 \circ f_4 \circ f_5$$

The Jacobian of this function follows:

$$J_f = J_{f_1} \times J_{f_2} \times J_{f_3} \times J_{f_4} \times J_{f_5}$$

A fixed-point of the function f, that is $f(\{\mathbf{A}, \mathbf{L}\}) = \{\mathbf{A}, \mathbf{L}\}$ defines an equilibrium of the system.

We can use the Jacobian to speed up the computation of the fixed-point algorithm.

E Data Appendix

E.1 ECB data warehouse

We collect interest rate series, banking spreads, country-specific interest rates for household deposits, mortgages, corporate loans, and corporate deposits. Specifically, we gather the volumes on the interbank market, the EURIBOR interest rates, the policy rate, and various other interest rates from the MIR dataset. We collect the money market volumes and rates using the EONIA and MMS/MMSR datasets, and recover the aggregate balance sheet exposures of the financial sector from the SHS/S, BSI and C/SEC datasets. All of these series are updated using the most recent data available at the date this paper is written.

E.2 Banque de France

The Banque de France has provided us with several key regulatory datasets that we can merge together using bank-level identifiers. All datasets are anonymised by the Banque de France, and the last period of observation is Q4 2021. While the starting date for available data differs between dataset, we have chosen to start data collection on Q1 2013 for two main reasons: First, this ensures that we have data points in every single dataset provided by the Banque de France during the whole time period. Second, this start date is just before Basel III regulation was released. At this point in time, the specifics of the regulation were common knowledge, and it seems reasonable to assume that banks were forward-looking enough to start considering Basel III regulation in their decision-making. Such an assumption is crucial for our empirical setup. To reconstitute the balance sheet of the bank, we merge the different datasets available to us and aggregate the data items into 12 mutually exclusive categories on the asset side and 12 mutually exclusive categories on the liability side. The high degree of granularity of our data allows us to choose among different level of aggregation for balance sheet items, the trade-off being that we want to keep the model parsimonious while only bundling together balance sheet items that have similar characteristics. These categories are presented in Table A1. We exclude the off-balance sheet items at the time being to preserve the simplicity of the analysis.

E.2.1 New loans – CONTRAN

The dataset reports detailed information on new loans issued by banks, on a monthly basis. It provides data on interest rates and volumes, but does not include information on the outstanding credit of the borrower. We use this dataset to compute interest rates for new loans in the preliminary regressions, as well as the size of the outside market share in the mortgage and corporate lending markets.

E.2.2 Credit registry – SCR

We observe all outstanding credit provided to private firms (approximately 1.5 million unique firms) and local public administrations (approximately 2100 unique administrations) for every bank-borrower relationship, as long as the total exposure of the bank – including credit lines – stands above 25,000 . We define outstanding credit in quarter t as the average over the 3 months of the quarter. The dataset includes municipal-level geographic information on the borrower, which we use to compute instrumental variables. We use this dataset in section 4 to run a reduced form analysis à la Khwaja and Mian (2008).

E.2.3 Deposits and Loans databases – INTENCO,INTEDEPO,iMIR

These datasets are part of the reporting framework of the Banque de France or the European Central Bank. We observe the volume and rates, at a monthly level, for different loans and deposit products offered by banks. We aggregate these at a quarterly level, taking the volume-weighted interest rate as the rate for the quarter. The iMIR dataset provides us with curated interest rates for a subsample of banks, while the INTENCO and INTEDEPO dataset

E.2.4 Interbank Exposures – ITB

We recover the interbank exposures from the ITB datasets. This allows us to compute the net position on the interbank market of individual banks, from which we exclude the intra-group credit positions – we take intra-group credit as out of the decision making of the bank, akin to an exogenous shift to bank equity on the liability side and to central bank reserves on the asset side.

E.2.5 Securities Holdings Statistics – SHS

We use a granular version of the SHS dataset that was made available to us at the French level, to compute the aggregate balance sheet positions of every sector of the French economy in specific assets categories. Specifically, we use this to compute the outside share on the deposit markets for household and non-financial corporations, by aggregating their holdings of highly liquid assets such as money market fund shares or government bonds. We also use SHS to gauge the share of balance sheet expanding QE transactions – where nonbanks are the counterparty to the central bank – and find results in line with Rogers (2022).

Assets	**Liabilities**
Equity Investment	*Demand deposits of non-households*
Loans to financial corporations	*Demand deposits of households*
Mortgage loans to non-households	*Time deposits of non-households*
Mortgage loans to households	*Time deposits of households*
Long term loans to non-households	Withdrawable special saving deposits of non-households
Long term loans to households	Withdrawable saving accounts of households
Short term loans to non-households	Locked saving accounts of non-households
Short term loans to households	Locked saving accounts of households
Safe asset investments	Central bank funding
Money market lending	Money market borrowing
Other asset	Other liabilities
Reserves	**Equity**

Table A1: Standardized balance sheet for French data

Notes: This Table illustrate the standardized balance sheet of the French bank in our data. We write the name of the balance sheet item in *italics* to distinguish between markets where we model the demand side of the market and bank's market power and the markets where we do not. Moreover, we write the name of the balance sheet item in **bold** if the item is exogenous for banks' balance sheet optimization.

E.3 Bureau van Dijk's BankFocus

We exploit the BankFocus dataset's extensive coverage of bank balance sheet data from Europe at the yearly level. One of the main downside of this dataset is that it often reports the subsidiary banks as separate entities, without providing indicators as to which banks belong to the same banking group. To avoid double counting of bank assets, we focus on the 152 most important banks in the Eurozone. We choose these banks by collecting from the European Banking Authority (henceforth EBA) the list of all the banks that have taken part in EBA's stress tests between 2014-2023.[36] Legal entity identifiers (LEI) allow us to match 146 of these banks to BankFocus data. To

[36]The stress test in 2014 took part 123 banks, while in the latter years the number of banks was generally around 50, at which point they cover about 70% of EU bank assets. The banks in the sample cover around 85% of total bank assets in Eurozone.

account for the few duplicates, absent other information, we use the observation that reports the largest bank assets[37]. If the values of total assets are equal, but the same does not hold for other variables, we average the values between the duplicates to generate unique observations for that bank-year pair. We merge the data and divide the balance sheet items into 5 mutually exclusive categories on the asset side and 5 mutually exclusive categories on the liability side. We exclude the off-balance sheet items for simplicity. These categories are presented in Table A2.

Assets	**Liabilities**
Household loans	*Customer deposits*
Corporate loans	*Bank deposits*
Government securities	Long term borrowing
Other Assets	Other liabilities
Reserves	**Equity**

Table A2: Standardized balance sheet for European data
Notes: This Table illustrate the standardized balance sheet of the European bank groups in our data. We write the name of the balance sheet item in *italics* to distinguish between markets where we model the demand side of the market and bank's market power and the markets where we do not. Moreover, we write the name of the balance sheet item in **bold** if the item is exogenous for banks' balance sheet optimization.

E.4 Additional details about Banque de France data

Here we list different data tables that we have at our disposal from Banque de France and what they contain.

1. **SHS-France**: This database contains detailed security by security holdings by sectors (Banks, Households, etc.) in France. It includes information on the price and characteristics of these securities.

2. **M-INTDEPO**: This databases reports bank-by-bank aggregate amounts for deposit products and the related monthly interest rate flows. This allows for the computation of interest rates paid by French banks on their deposit products.

3. **M-INTENCO**: This databases reports bank-by-bank aggregate amounts for lending products and the related monthly interest rate flows. This allows for the computation of interest rates charged by French banks on their lending products.

4. **IMIR-ENCOURS**: This database reports bank-by-bank aggregate lending, and interest rate flows.

[37]The exception is HSBC and Barclays, where we take the continental Europe entity as the entity of interest instead of the banking group.

5. **M-RESEAUG**: This database reports aggregate lending and deposits for bank branches, for various counterparty categories. It specifically includes loans to state entities.

6. **ITB-nRESI-EC, ITB-RESID-EC**: Reports exposures (both in Euro and in foreign currencies) to interbank lending and deposits, both towards central bank and towards other credit institutions. The ITB-RESID-EC dataset distinguishes between secured and unsecured products.

7. **M-TITPRIM**: Reports bank-by-bank aggregate holdings for different security and counterparty types. Both the accounting value and the market value of the assets can be observed in the dataset.

8. **ENGAG-INT**: The database reports the international exposure of the bank, country-by-country, instrument-by-instrument.

9. **M-CONTRAN**: New euro-denominated credit contracts issued by French banks concluded with individuals, non-financial companies, sole proprietors, non-profit institutions and local public administrations. A new contract is defined as any new loan or any old contract that has been bought by the bank during the period. The database provides the amount and the interest rates of the reported loans, and provides a unique loan identifier that allows tracking a specific loan over time.

10. **COTA**: The dataset reports the company ratings issued by the Banque de France, which in combination with the credit registry allows to gauge the riskyness of the lending portfolio of banks.

11. **NCE**: Subsample of new lending contracts matched with data on the borrowing companies (size, credit risk).

12. **SCR**: Credit registry. Collects data on borrowers with exposure above 25,000 euros towards banks operating in France. It reports outstanding amount of credit, interest rates, as well as the geographic location of borrowers.

13. **SITUATION-EC**: Banks' balance sheet items obtained from bank regulatory filings. Provides a summary of activities by operation and geographical area.

14. **M-SITMENS**: Monthly aggregate banks' balance sheet items. The level of detail is lower than in the SITUATION-EC dataset.

E.5 Additional details about European level data cleaning

E.5.1 Excluding the non-European assets and liabilities from bank balance sheets

Some banks in our sample are very international. To generate a bank-level dataset where a bank's balance sheets are purged from asset and liability holdings based outside of Europe we use data from EBA based on their EU-wide stress testing[38]. These data contain granular reporting of the risk exposure of each stress-tested bank's assets at the end of the previous year that stress test was conducted. We utilize data on stress tests from 2014, 2016, 2018, 2021 and 2023. In each of these years, there were 123, 51, 48, 50 and 70 banks tested respectively. Under the assumption that the bank's share of total *risk exposure of holdings* held within Europe is proportional to the share of total *assets* held in Europe, we can use these data to determine what fraction of bank's assets are invested in Europe versus abroad. Then we can simply scale the asset items in the balance sheet of banks in our BankFocus sample with the fraction of total assets that the bank holds in Europe. So, to be precise for asset item j in bank i's balance sheet held in Europe is defined as $A_{ij}^{Europe} = A_{ij}^{Total} \times (1 - share\,of\,foreign\,assets_i)$ where A_{ij}^{Total} is the total reported amount in annual report while $share\,of\,foreign\,assets_i$ is calculated from stress test data. Note that for simplicity, we assume that this bank's aggregate level distinction to European and non-European assets is reflected also at the sub-item level.

Unfortunately, this stress test data does not contain information about how each bank's liability base is shared among different countries within Europe or abroad. To overcome this limitation we use data about European G-SIIs from EBA website.[39], which effectively represents a subset of the banks in the larger sample. Due to their annual risk monitoring EBA reports each year for the European G-SIIs the cross-jurisdictional claims and cross-jurisdictional liabilities for each the G-SII bank. Using these values we can calculate the share of cross-jurisdictional claims or cross-jurisdictional liabilities held in EBA's jurisdiction versus outside of it.

The benefit of doing so is that we can then compare how much the share that bank holds in foreign (non-European) assets explains the bank's share in foreign (non-European) liabilities. If these two measures are highly correlated, then we can use the information that we have about asset side allocation between domestic versus foreign countries in the stress-test data to make reasonable predictions about the corresponding allocation in the liability side. Table A3 presents the results for the G-SII banks. As expected, the foreign share in assets and liabilities are highly correlated, implying that 1 pp increase in $Share\,of\,foreign\,claims$ corresponds 0.83 pp increase in foreign liabil-

[38]https://www.eba.europa.eu/risk-and-data-analysis/risk-analysis/eu-wide-stress-testing

[39]https://www.eba.europa.eu/risk-and-data-analysis/risk-analysis/risk-monitoring/global-systemically-important-institutions-g-siis

Table A3: Relationship between foreign asset share and foreign liability share

Dependent Variable:	Share of foreign liabilities	
Model:	(1)	(2)
Variables		
(Intercept)	-0.0096	
	(0.0222)	
Share of foreign claims	0.8322***	0.8385***
	(0.0517)	(0.0517)
Fixed-effects		
year		Yes
Fit statistics		
Observations	209	209
Adjusted R^2	0.63185	0.63237

Clustered (LEI) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

This Table presents relatinship between foreign claim share and foreign liabilty share for each European G-SIB bankbetween 2014-2020.

ities. Moreover the the intercept term is effectively zero. using the fitted values from the model in Column (1) implies that a banks that has 10% of its total assets invested overseas has on average 8.3% of its total liabilities also coming from overseas. Now using this number and the asset side data we do a similar procedure as described above where we restrict the sample to European liabilities only. So for a liability item j in bank i's balance sheet, the share of that liability held in Europe is defined as $L_{ij}^{Europe} = L_{ij}^{Total} \times (1 - share\, of\, foreign\, liabilities_i = L_{ij}^{Tota} \times (1 - 0.83 \times share\, of\, foreign\, assets_i)$.[40]

E.5.2 Cross-country deposit/loan allocation

TBD

E.5.3 Bankfocus data details

We use the following data items in constructing the balance sheet. For the liabilities:

1. LT Borrowings and Debt Securities at Historical Cost DATA60500
2. Customer deposits DATA60300
3. Bank deposits DATA60400
4. Total liabilities DATA61900

[40]Since stress tests do not occur every year and not every bank appears in every stress test we use the average $share\, of\, foreign\, assets_i$ for that i every stress test year that it appears in to fill the missing observations in the time series.

For assets

1. Government securities DATA81100
2. Cash Balances at Central Bank DATA91010
3. Loans DATA90000
4. Total assets DATA99240

As outlined earlier, only a few banks report their how their loans decompose into corporate loans and household loans. Thus we do this decomposition in two steps. In the first step, we decompose the total loans to these shares using CapitalIQ data, and then we multiply these shares with the BankFocus-based value of total loans to get household loan and corporate loan levels in absolute terms. This way we minimize the mixing of balance sheet items between different datasets.

To obtain proxy for ΔQ_i we calculate the "Net Interbank Borrowing" as "Deposits from banks (Item 91400)-Loans and advances to banks (Item 90400). The government securities (Item 81100). We treat the reserves held at the central bank as reserve endowments $\bar{Q}_i$ (Item 91010)

E.5.4 Regulatory ratios

We model the regulatory ratios using the weights presented in tables A5 to A8, building upon the assumptions presented in table **??**. We collect the data data directly from published regulation and guidelines, as described in and when applicable we follow the prior literature—e.g for LCR as in Sundaresan and Xiao, 2024 and for NSFR as in Hoerova et al., 2018.

Table A4: Assumption used when building the ratios

Assumptions;NSFR/LCR/CET1		
Item	Assumption	Source
Household deposits	HD1: 60% Share of demand deposits	INTDEPO/ENCO
	HD2: 66% Insured (= stable) share of demand deposits	INTDEPO/ENCO
	HD3: 30% of time deposits with <1 year maturity	INTDEPO/ENCO
Corporate deposits	C1: 65% Share of demand deposits	INTDEPO/ENCO
	C2: 50% of deposits by SME	INTDEPO/ENCO
	C3: 50% of time deposits with <1 year maturity	INTDEPO/ENCO
Deposits	S1: 70% Household vs corporate deposit share	INTDEPO/ENCO + ECB data
Maturity	M1: 1/12th of time deposits with <1 year maturity mature in the next 30 days	Homogenous distribution assumption
	M2: 20% of loans mature in <1 year	INTDEPO/ENCO + ECB data
Corporate Deposits	OW1: 20% of operational deposits, 80% of wholesale deposits by volume.	EBA RISK DASHBOARD DATA AS OF Q4 2022
	OW2: 100% of time deposits are wholesale deposits	EBA RISK DASHBOARD DATA AS OF Q4 2022
Covered Bonds	CB1: 50% of extremely high quality covered bonds	
Deposit insurance SME	DI1: 20% of deposits from SME insured	EBA/Rep/2023/39, Figure 4
Bank Deposits	Itb1: 95% of Bank deposits mature in less than 1 month	Assumption
Corporate Debt	CD1: 50% of outstanding volume is SME credit	Observation from M_Contran
	CD2: 50% of SME credit is collateralized with commercial mortgages	Observation from M_Contran
	CD3: 65% of Large firm credit is collateralized with commercial mortgages	Observation from M_Contran
	CD4: Average rating for rated firms is BBB	Assumption
Corporate Bonds	Bd1: 50% covered bonds in LT non gov bond holdings	Assumption
	Bd2: ST rating is AA or above	Assumption
Households	HH11: 55% of outstanding volume collateralized	Observation from M_Contran

This table describes the assumptions required to build the regulatory ratios from the observed data. We built these assumptions using external data sources, listed in the third column. The first column lists the assumption name, used in the ratio table, and the second column details the assumption.

Table A5: NSFR

NSFR Observed Item	(Assumed) Share	Source: Basel III documentation Regulatory Item	Regulatory weight	Replication weight
Required Funding				
Government securities	100%	Government-issued securities	15%	0%
	0%	Regional-gov-issued securities	15%	
	0%	Public-Sector entity	15%	
Monetary and financial insitutions	100%	Institutions	∼50%	30%
Corporate Debt	18%	Large firm credit, non collateralized	78% (85% for loans maturing in >1 year, 50% otherwise)	65,50%
	32,50%	Large firm credit, mortgaged	78% (85% for loans maturing in >1 year, 50% otherwise)	
	25,00%	SME credit, non collateralized	78% (85% for loans maturing in >1 year, 50% otherwise)	
	25,00%	SME credit, mortgaged	78% (85% for loans maturing in >1 year, 50% otherwise)	
Reserves	100%	Reserves	0%	0%
Other Assets	5%	Tangible Assets	100% (fixed assets)	45,31%
	35%	Corporate Bonds	36,25% RSF (assuming 50% at 15% RSF and 50% at 50% RSF)	
	10%	Reverse Repo	10% RSF (p9 of document)	
	25%	Loan to Banks (Institutions)	32,5% RSF (assuming 50% at 15% RSF, 25% at 50% RSF and 25% at 65% RSF)	
	25%	??????	100% (conservative estimate)	
Household lending	55%	Collateralized mortgage credit	62% (65% for loans maturing in >1 year, 50% otherwise)	69,65%
	45%	Uncollateralized loan	78% (85% for loans maturing in >1 year, 50% otherwise)	
Available Funding				
Equity	100%	Regulatory Capital	100%	100%
Customer deposits	28%	Insured household demand deposits	95%	88,92%
	14%	Uninsured househould demand deposits	90%	
	8%	<1 year mat HH term deposits	90%	
	10%	SME demand deposits	90%	
	3%	<1 year mat SME term deposits	90%	
	10%	Wholesale corporate deposits	50%	
	3%	<1 year mat large firm term deposits	50%	
	20%	Share of >1year HH dep	100%	
	5%	Share of >1year corp dep	100%	
Central bank funding	???%	Central bank funding maturing in <6 months	50%	???%
Bank Deposits	100%	Bank funding	0%	0%
Long term funding	100%	Any funding >1 year maturity	100%	100%
Other liabilities	100%	Conservative 20%	20%	20%

Table A6: LEV

Assets	Asset weights	Liabilities	Liability weights
Reserve	1	CB Funding	0
Equity	1	Eqty	1
Loans Fin Corps	1	WithdrawSpeSavHH	0
ST Loans HH	1	WithdrawSpeSavCorp	0
LT Loans HH	1	LockedSpeSavHH	0
ST Loans Corps	1	LockedSpeSavCorp	0
LT Loans Corps	1	TimeDepHH	0
Mortgages HH	1	TimeDepCorp	0
Mortgages non HH	1	WithdrawDepHH	0
Money Market	1	WithdrawDepCorp	0
Safe Assets	1	Money Market	0
Other Assets	1	Other	0

Table A7: LCR

LCR	Source: Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools (documentation)	HQLA=L1A+L2A-max(L2A-(2/3)L1A,0)		
Observed Item	(Assumed) Share	Regulatory Item	Weight	Replication weight
Stock of HQLA				
Government securities	100%	Government-issued securities	100%	
	0%	Regional-gov-issued securities	100%	100%
	0%	Public-Sector entity	100%	
Reserves	100%	Reserves	100%	100%
Other Assets	35%	Corporate bonds (including EHQCB)	23% (CB1, Bd1, Bd2)	9,30%
	25%	???	5%	
Monetary and financial insitutions	100%	Institutions	0%	0%
Cash Outflows (Liabilities)				
Equity	100%	Regulatory Capital	0%	0%
Customer deposits	28%	Insured household demand deposits	3%	8,61%
	14%	Uninsured househould demand deposits	5%	
	1%	<1 month mat HH term deposits	15%	
	2%	Operational SME demand deposits	21%	
	8%	Wholesale SME demand deposits	36%	
	0%	<1 month mat SME term deposits	40%	
	10%	Wholesale corporate deposits	40%	
	0%	<1 month mat large firm term deposits	40%	
	27%	Share of >1month HH dep	0%	
	10%	Share of >1year corp dep	0%	
Central bank funding	5%	Central bank funding maturing in <6 months		5%
Bank Deposits	100%	Bank funding	95% (Itb1)	95%
Long term funding	100%	Any funding >1 year maturity	1%	1,190%
Other liabilities	30%	Repo	10% (assumption)	3%
	70%	Other	0%	0%
Cash Inflows (Assets)				
Corporate Loans	2%	Corporate Loans maturing in <30 days	50%	0,833%
Other Assets	5%	Tangible Assets	0% (fixed assets)	
	35%	Corporate Bonds	0%	
	10%	Reverse Repo	0% (conservative estimate)	23,75%
	25%	Loan to Banks (Institutions)	95%	
	25%	??????	0% (conservative estimate)	

Table A8: CET1

CET1	Source:	EUR-Lex regulation 575/2013		
Observed Item	(Assumed) Share	Regulatory Item	Regulatory weight	Replication weight
Government securities	100%	Government-issued securities	0% (Article 114)	
	0%	Regional-gov-issued securities	0% (Article 115)	0%
	0%	Public-Sector entity	50% (Article 116, assumption debt rating A and above)	
Monetary and financial insitutions	100%	Institutions	30% (Articles 120-121, assumption 70% at 20% risk weight, 30% at 50% risk weight)	30%
Corporate Debt	17,5%	Large firm credit, non collateralized	100% (Article 122, assumptions CD1, CD3, CD4)	
	32,50%	Large firm credit, mortgaged	50% (Article 125, assumptions CD1,CD3, CD4)	65,50%
	25,00%	SME credit, non collateralized	75% (Article 123, assumptions CD1, CD2)	
	25,00%	SME credit, mortgaged	50% (Article 125, assumptions CD1,CD2)	
Reserves	100%	Reserves	0% (Article 113)	0%
Other Assets	5%	Tangible Assets	100% (Article 122, assumptions CD1, CD3, CD4)	
	35%	Corporate Bonds	60% (Bd1, Bd2, Article 122, Article 129)	
	10%	Reverse Repo	20% (Articles 120-121, assumption 100% at 20% risk weight due to collateral)	
	25%	Loan to Banks (Institutions)	30% (Articles 120-121, assumption 70% at 20% risk weight, 30% at 50% risk weight)	60,50%
	25%	??????	100% (conservative assumption, unknwown composition)	
Household lending	55%	Collateralized mortgage credit	35% (Article 124, assumption HH1)	53,00%
	45%	Uncollateralized loan	75% (Article 122, assimption HH1)	

F Figures

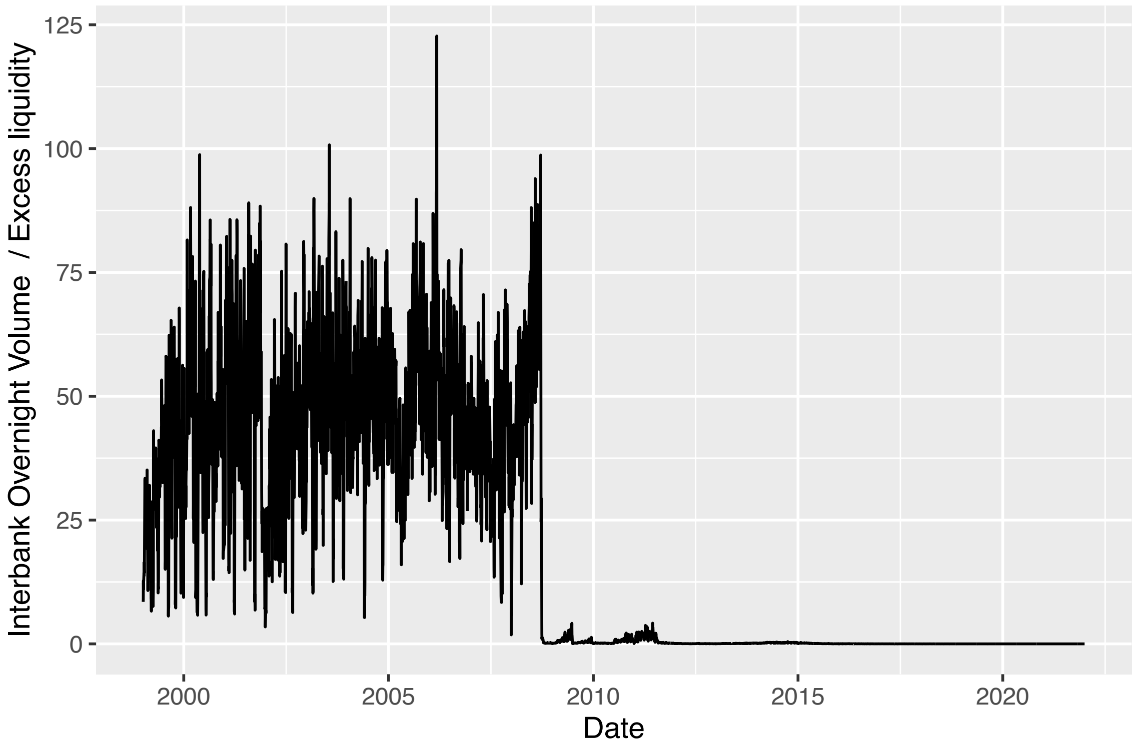
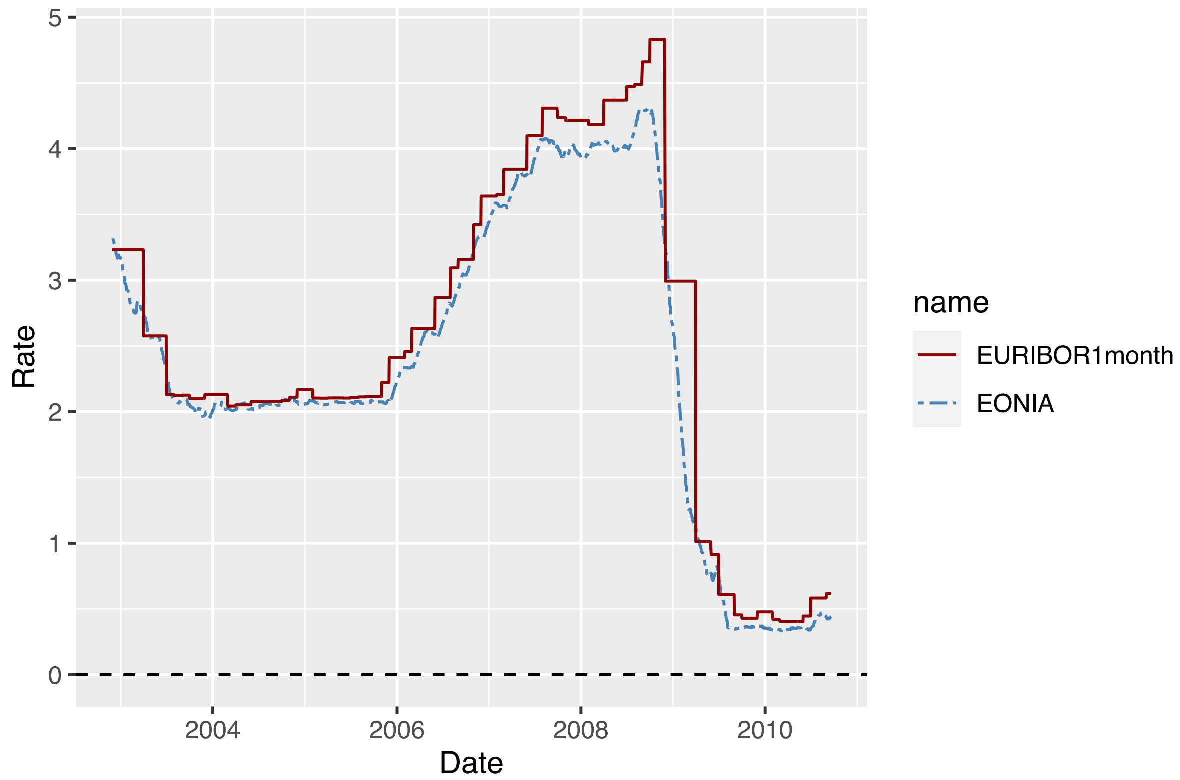
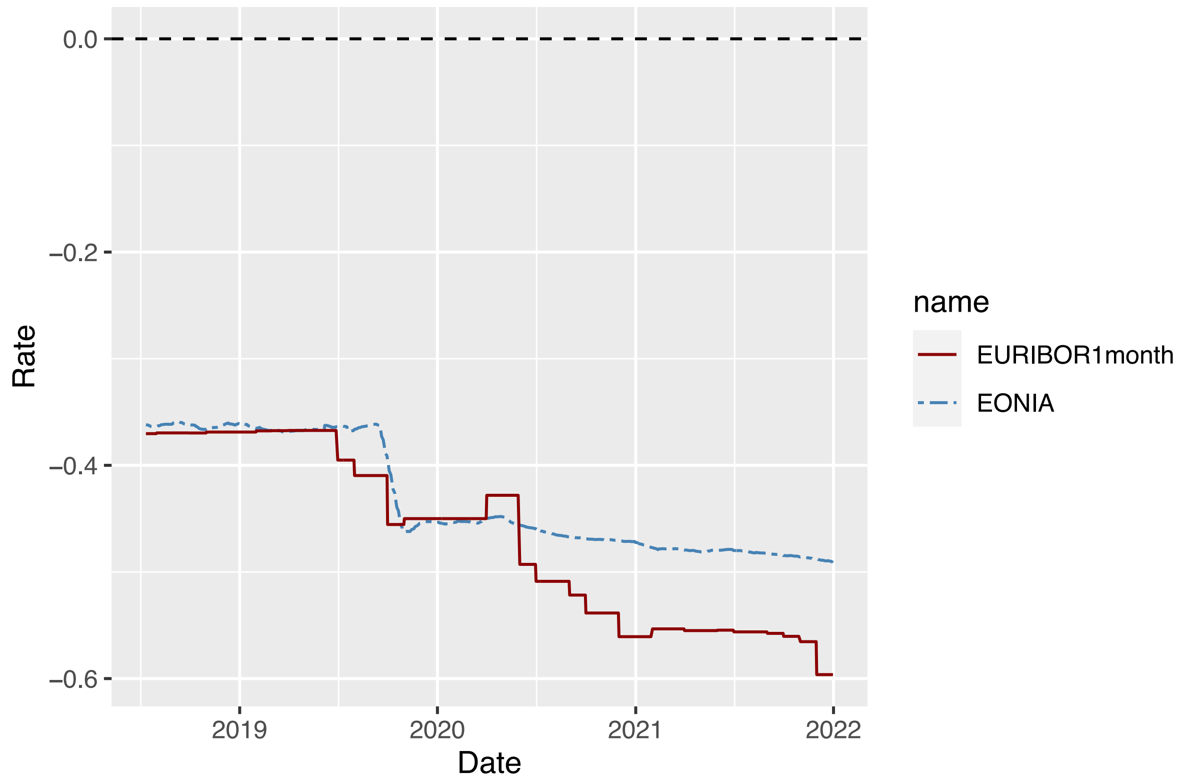


Figure A1: Overnight reserves market volume expressed as a multiple of excess liquidity



(a) Rates pre unconventional monetary policy



(b) Rates post unconventional monetary policy

Figure A2: Interbank spread before and after QE

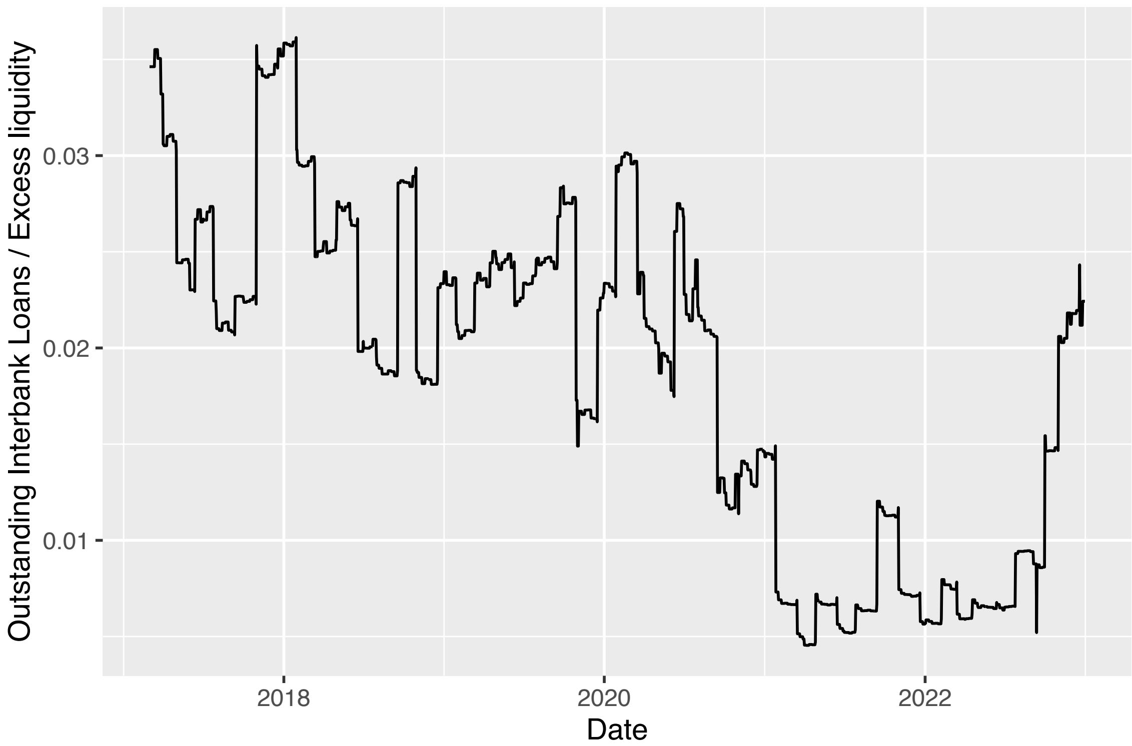
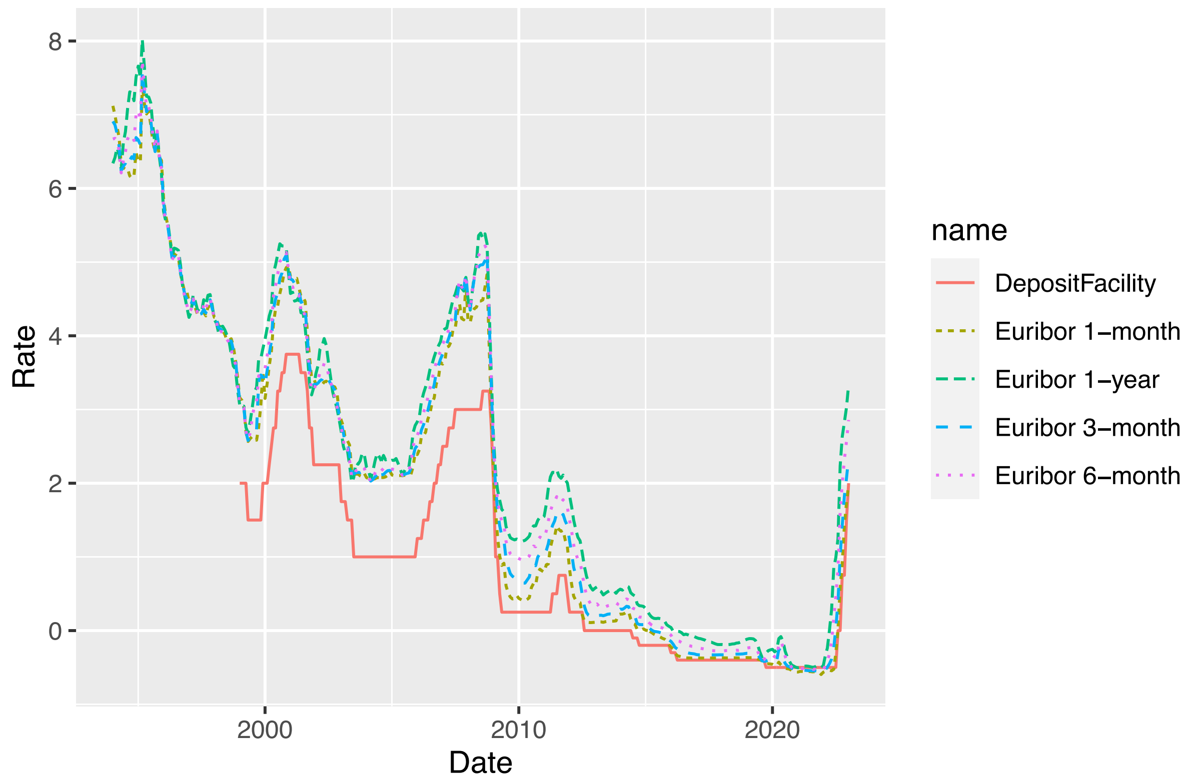
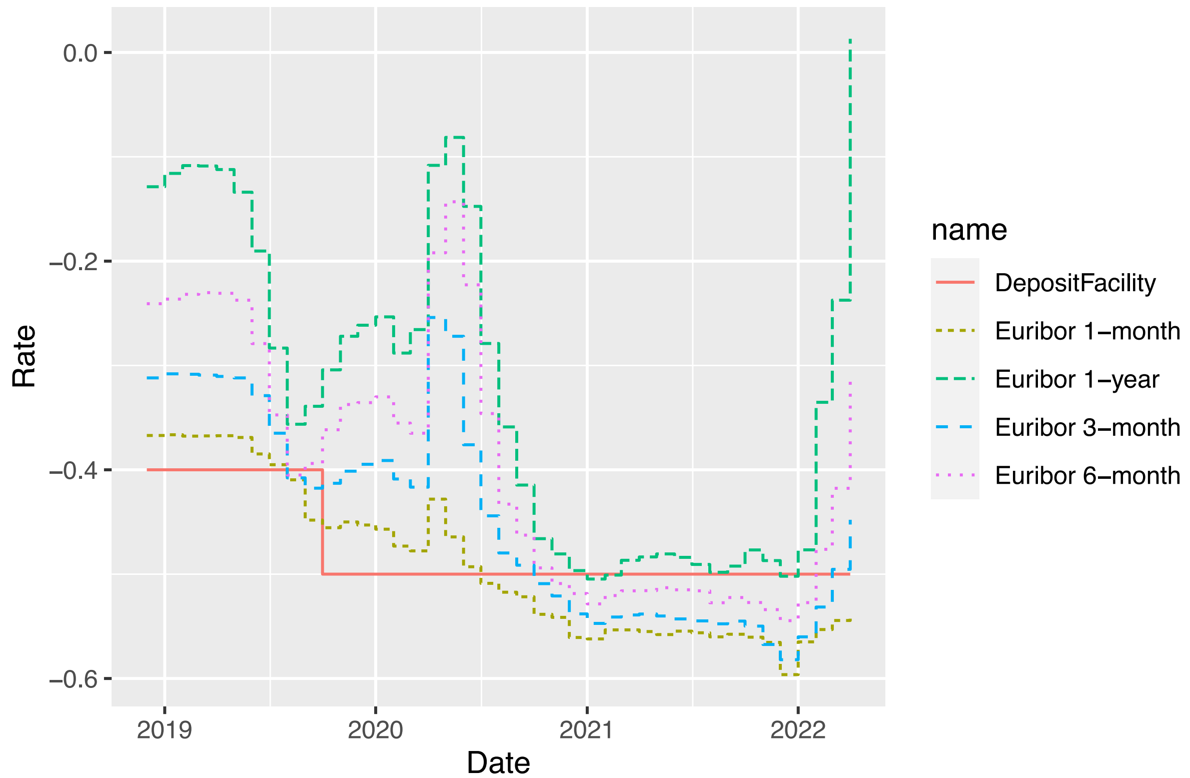


Figure A3: Outstanding Unsecured Inter-Bank Debt As a Fraction of Reserves



(a) Euribor vs Deposit facility rate



(b) Euribor vs Deposit facility rate: Zoom

Figure A4: Euribor plotted against the deposit facility rate

G Details on the construction of covariance matrix and rate series

We calibrate the covariance matrix $\mathbf{\Sigma}$ items using estimates from representative covariance matrix which we calculate based on aggregate return series collected from the ECB data warehouse. For assets or liability items we consider as "risk-free" we set the return series as zero, which correspondingly generates zero values in the resulting covariance matrix in the rows and columns that occupy these balance sheet items.

For the liability items we flip the sign of these return series before calculating the covariance matrix to be consistent with the model.[41]

H Comparative statistics of the empirical model

H.0.1 Reserve trading volume

Corollary 1. *Assume for simplicity that reserves are riskless assets (i.e. they do not enter the matrix Σ), then*

$$\Delta Q_{i,R} = \frac{R_{DF} - R_{ITB} - \sum_k \lambda_{i,k}\omega_{k,R}}{\varphi} E_i \tag{H.24}$$

This implies that the reserve market volume is given

$$\sum_i |\Delta Q_{i,R}| = \frac{1}{\varphi} \sum_i E_i |(R_{DF} - R_{ITB} - \sum_k \lambda_{i,k}\omega_{k,R})|$$

Using the market clearing that $\sum_i \Delta Q_{i,R} = 0$ we get

$$R_{DF} - R_{ITB} = \sum_k \sum_i \frac{E_i}{\sum_i E_i} \lambda_{i,k}\omega_{k,R} = \sum_k \bar{\lambda}_k \omega_{k,R} \tag{H.25}$$

and plugging this back to reserve volume equation we can write it as

$$\sum_i |\Delta Q_{i,R}| = \frac{1}{\varphi} \sum_i E_i | \sum_k (\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}|$$

This implies that the trading volume is increasing in heterogeneity in constraints $|\sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}|$ and decreasing in the cost of trading φ.

To understand why the increase in reserves could all else equal impact the reserve trading, assume ECB injects dQ_R reserves into the system so that they get allocated to different banks exogenously so that $dQ_{i,R} = share \times dQ_R$

[41] We use monthly return data so we annualize the sample moments by multiplying the resulting covariance matrix by 12.

$$\frac{dVolume}{d\hat{Q}_R} = \frac{1}{\varphi}\sum_i \underbrace{\frac{\sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}}{|\sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}|}}_{\text{Relative standing}} \underbrace{\frac{\partial \sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}E_i}{\partial \hat{Q}_{i,R}}}_{\text{Net impact of reserves}} \underbrace{\frac{d\hat{Q}_{i,R}}{d\hat{Q}_R}}_{\text{Bank i share of injection}}$$

using the fact that for a function $u(x)$, $\frac{d|u|}{dx} = \frac{u}{|u|}\frac{du}{dx}$. We can also reformulate this as

$$\frac{dVolume}{d\hat{Q}_R} = \frac{1}{\varphi}\sum_i \frac{\sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}}{|\sum_k(\bar{\lambda}_k - \lambda_{i,k})\omega_{k,R}|}\left[\frac{d((R_{DF} - R_{ITB})E_i)}{d\hat{Q}_{i,R}} - \frac{\partial \sum_k \lambda_{i,k}\omega_{k,R}E_i}{\partial \hat{Q}_{i,R}}\right]\frac{d\hat{Q}_{i,R}}{d\hat{Q}_R}$$

The sign and magnitude of these terms will generally determine if the direct impact of reserve injection is positive or negative.